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Using Mined Space for Long-Term Retention of Nonradioactive Hazardous Waste Volume 2. Solution Mined Salt Caverns

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USING MINED SPACE FOR LONG-TERM RETENTION OF NONRADIOACTIVE HAZARDOUS WASTE

Volume 2 - Solution Mined Salt Caverns

by

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16. ABSTRACT

This two-volume report assesses the current status of using mined-space for long-term retention of nonradioactive hazardous waste. Volume 1 updates previous studies conducted in 1974 and 1975 and examines published literature, determines involvement of government agencies, reviews regulatory and permitting requirements, and identifies existing mines for a potential demonstration project.

Volume 2 expands the definition of mined space to include that created by solution mining of salt. This report examines the extent of salt deposits in the continental United States, relates the salt deposits to waste generating regions, examines the variances in salt chemistry for the various deposits, describes the methods for creating solution mined caverns, discusses design and operation considerations, discusses projects proposed by industry, discusses advantages of the concept, and discusses needed research.

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FOREWORD

The Environmental Protection Agency was created because of increasing public and governmental concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimonies to the deterioration of our natural environment. The complexity of the environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is the first necessary step in problem solution, and it involves defining the problem, measuring its impact, and searching for solutions. The Hazardous Waste Engineering Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and the solid and hazardous waste pollutant discharges from municipal and community sources; to preserve and treat public drinking water supplies; and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research and is a most vital communications link between the researcher and the user community.

The original studies of using mined space for long-term retention of nonradioactive hazardous waste were done 10 years ago. This report documents development of the concept since then. The assessment includes applicable regulatons, permitting regulations, and technological advances that have expanded the definition of mined space to include solution-mined salt caverns as well as conventionally mined space. The use of mined space for retaining hazardous waste provides an environmentally acceptable alternative for storing untreatable and residual wastes that are difficult or expensive to manage with existing technology.

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ABSTRACT

This report is the second of a two-volume document that assesses the current status of using mined space for long-term retention of nonradioactive hazardous waste. This volume expands the definition of mined space to include that created by solution mining of salt. The concept of using solution mined caverns in salt for storing hazardous waste has recently been proposed by industry as an economically viable method for disposal of certain hazardous wastes. This report examines the extent of salt deposits in the continental United States, relates the salt deposits to the U.S. Environmental Protection Agency (EPA) waste-generating regions, examines the variances in salt chemistry for the various deposits, describes the methods used for creating solution mined caverns, discusses the design and operation considerations for this concept, examines the environmental considerations, briefly discusses projects proposed by industry, enumerates the advantages of the concept, and identifies needed research to further the concept.

Volume 1 updates previous studies conducted in 1974-77, examines recent literature published on the subject, determines the involvement of government agencies, reviews regulatory and permitting requirements, and selects existing mines for a demonstration project.

This report was submitted in fulfillment of Contract No. 68-03-3191 by Fenix & Scisson, Inc. under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period August 18, 1983 to January 5, 1985, and work was completed as of August 10, 1984.

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SECTION 1

INTRODUCTION

The continued health of an industrial society depends on its ability to dispose of the hazardous wastes it creates in an environmentally acceptable manner. This fact has been recognized for many years by government, environmental activists, and concerned industry. Concern over the issue is demonstrated by creation of the U.S. Environmental Protection Agency (EPA) and the enactment of numerous Federal laws and regulations.

The search for environmentally acceptable and economically viable methods for hazardous waste storage and disposal has been continuing, with much debate among legislators, industry, and environmentalists. A national waste management program was formed with enactment of the 1976 Resource Conservation and Recovery Act (RCRA) and the hazardous waste regulations promulgated under RCRA by EPA.

The present methods of hazardous waste disposal are: deep well disposal, engineered landfills, land treating of hazardous waste, and incineration.

The principal limitations of present disposal and storage methods are:

- Deep Well Disposal - This method can handle only liquid wastes, and the direction and spread of the liquid is essentially controlled by the underground formation characteristics once it is injected. Though deep well disposal is widely used for liquid waste and brine disposal, present technology cannot assure that the practice will not pollute usable aquifers at some future date.

- Engineered Landfills - Engineered landfills have been and are being used for disposal of hazardous sludges and liquids. This disposal concept can provide environmentally sound, long-term containment in properly designed landfills. However, poorly designed landfills constructed in the past have encountered leakage, storm runoff, and high ground water problems. Review of past problems indicates that with proper engineering design and construction this method of hazardous waste disposal may remain a viable option for certain wastes and certain locations.

- Land Treatment - In this method of disposal, the waste sludges or liquids are spread on tillable land. This method has limited applicability because of the large land area required and the relatively slow process of biodegradation and assimilation of the sludges into the land. If not properly designed and operated, buildup of toxic materials in the soil and subsequent leaching of this material into surface and ground water may occur.

- Incineration - The use of incineration for waste disposal is limited to wastes that can burn without producing uncontrollable air pollutants and ash which may contain toxic and harmful residues that make disposal difficult. This method is suitable for many waste streams, but it can be expensive and can require the use of supplementary fuels to maintain combustion.

A need remains for an ultimate disposal technique that can handle the residues from the other methods. The use of underground mined space appears to provide a technically and economically feasible method of permanent storage. The advantages of solution mined space for hazardous waste storage would appear to be the following:

- Hazardous waste can be completely isolated from the surface environment.

- Wastes emplaced in solution mined salt caverns should be isolated from the hydrological environment.

- Security can be readily maintained.

- Minimal maintenance should be required for solution mined caverns.

A disadvantage of solution mined space with respect to conventionally excavated mined space is that retrievability would not be practical if mixed wastes or in-situ solidified wastes were emplaced in solution mined caverns.

Purpose of Volume 2

The purpose of this second volume is to provide technical background on the use of solution mined salt caverns for the storage of hazardous waste, and to identify needed research to further the concept.

Organization of Report

Each volume of this report addresses a separate aspect of the use of mined space. Volume 1 includes a search for suitable existing, conventional, mined space, in room and pillar salt and limestone mines for a demonstration of the concept of waste retention in mined space. This volume includes a literature review, an assessment of the involvement of government organizations, and a review of regulations and permitting requirements.

Volume 2 consists of a geological, geographical, and environmental assessment of the potential use of solution mined space in salt domes and salt beds for hazardous waste storage. This concept appears to offer an economical alternative for the permanent retention of hazardous liquids and slurries. Th report includes a nationwide assessment of the occurrence of suitable salt deposits, the chemistry of the individual major deposits, a preliminary matching of the waste-generating regions to the salt deposits, the past history of the use of solution mined space for hydrocarbon storage, a description of the solution mining process, a discussion of design and operating factors, and recommendations for further research.

SECTION 2

CONCLUSIONS

1. Solution mined caverns in dome salt formations are being used for containment of crude oil by the U.S. Strategic Petroleum Reserve program.

2. If the hazardous wastes to be retained are compatible one with another, and with dome and bedded host rock salts and their brines, this method of waste retention might be used for permanent storage. Further study of the compatibility of hazardous wastes with other hazardous wastes and the compatibility of those wastes with dome and bedded host rock salts and their brines is required.

3. The desired type of salt deposits exist near major waste generation areas.

4. In-situ solidification of the hazardous waste in a solution mined salt cavern would reduce the risk of leakage in event of earthquake or inadvertent drilling into the cavern. Development of salt saturated hazardous waste/cement or polymer slurry formulations is required that will combine an acceptable fluidity during emplacement with adequate strength, life, and economy as in-situ solidified waste.

SECTION 3

RECOMMENDATIONS

1. Studies each should be made to establish compatibility of hazardous wastes with each other and with host rock salts and their brines.

2. Studies should be conducted to develop salt saturated hazardous waste/cement or polymer slurry formulations that will combine an acceptable fluidity during emplacement with adequate strength, life, and economy when solidified in-situ.

3. Preliminary feasibility studies including conceptual designs and order of magnitude cost estimates should be prepared for economic and environmental evaluation and consideration of demonstration of solution mined hazardous waste retention facilities.

SECTION 4

HISTORY OF HAZARDOUS WASTE STORAGE IN SOLUTION MINED SALT CAVERNS

The concept of storing liquid or slurry hazardous wastes in solution mined caverns in salt is not new. Mercury compounds have been permitted to accumulate in three salt caverns near a chlor-alkali plant in Saskatchewan, Canada and in salt caverns in Southwestern Ontario. A salt cavern in the Sarnia District of Southwestern Ontario serves as a repository for heavy chlorinated hydrocarbons displacing lighter waste to a disposal well. Three other caverns contain waste purge gas from a gas processing plant near Sarnia (1).

In 1938, Akzo, a chemical manufacturing firm in the Netherlands, started disposing of wastes from brine purification units into existing salt cavities in the Hengelo area. In 1965, they began using salt cavities for the disposal of salty drilling muds. In 1978, they began disposing magnesium chloride brine under the salt brine. It is also interesting to note that Akzo developed the original "string-of-pearls" concept wherein a series of waste disposal caverns are leached, one above the other, from a single deep solution well (2).

The Carey Salt Company has used worked-out brine cavities to dispose of waste calcium sulphate slurry from the refining process for over 30 years.

The International Salt Company at Watkins Glen, New York began placing the residual natural wastes from their salt production operation into three interconnected solution wells in 1971. The heavy metals were allowed to settle out in a solution cavern displacing the lighter brine to the surface for injection into a "black water" horizon called Cherry Valley. This disposal well was permitted by the Department of Environmental Conservation of the State of New York (3).

At least two waste management firms have proposed retention of hazardous waste in solution mined caverns.

Empak, Inc. of Houston, a waste management firm, applied to the Louisiana Department of Conservation for a permit to build a hazardous waste facility on the Vinton Salt Dome in southwest Louisiana. This proposal anticipates the creation of one 1,000,000 barrel solution mined cavern each year for the retention of hazardous waste (4). Since this project was announced, a state law was passed (in 1983) forbidding emplacement of hazardous wastes in salt domes for a period of two years to allow the state time to evaluate the proposed use prior to issuance of a permit. This proposal includes a unique cavern placement arrangement and Empak applied for a patent on this concept. This is the "string-of-pearls" design in which one deep well is used to create a series of individual caverns, one above the other. After the lowest cavern is filled, it is sealed and the next higher cavern is developed. The concept makes maximum use of the salt resource while minimizing drilling costs. The Empak caverns are to be evacuated to atmospheric pressure and then filled with waste slurry containing 10% to 30% solids by weight. Waste gases from the surface waste storage tanks and from the cavern during filling are to be vented through a scrubber and flare system to eliminate polluting emissions.

United Resource Recovery, Inc. of Houston, through Keysmith Corp. of Austin, submitted an application to the Texas Department of Water Resources (TDWR) for a permit to store hazardous waste in solution mined salt caverns in Boling Salt Dome in 1983. This application triggered a geologic study to evaluate the acceptability of using salt domes for waste disposal and to recommend guidelines for waste storage in domes. The Bureau of Economic Geology of the University of Texas at Austin has completed and published Phase I and Phase II findings of the study. In addition to identifying technical and geologic issues regarding such waste storage, these interim reports mention that solidifying chemical waste in a solution mined cavern might be a desirable technique for preventing rapid groundwater transport of the waste, and that it could also minimize the potential for release of lithostatically pressurized waste liquids if drilled into inadvertently.

The recent (fall 1984) reauthorization of the Resource Conservation and Recovery Act has a provision included in it which has banned bulk or non-containerized liquid hazardous waste disposal in solution caverns or underground mines constructed in dome or bedded salt bodies. This ban will remain in effect until the Environmental Protection Agency has determined through a series of findings, the feasibility of the concept and issued a permit for a specific facility. This new requirement has a direct impact upon and will delay the permitting of the proposed Louisiana and Texas facilities described above.

For additional sources of information on the storage, disposal, and retention of non-radioactive waste in solution caverns in salt refer to the bibliography.

Hydrocarbon Storage

No discussion of solution mined salt caverns would be complete without mention of the vast quantities of hydrocarbons stored in them. Although these hydrocarbons are not hazardous wastes, absolute containment has been required and proven. In 1983 there was a total of over 520 million barrels (42 gallons/barrel) of storage capacity in the United States for propane and other light hydrocarbons (5). In addition, there are nearly 500 million barrels of crude oil presently in storage in the U.S. Strategic Petroleum Reserve. The LOOP project in the Clovelly salt dome south of New Orleans has eight caverns capable of storing a total of over 30 million barrels of crude oil. Private natural gas companies have a total of over 20 million barrels of cavern storage space, with storage at wellhead pressures of up to 3,950 psi. With over one billion barrels of solution mined storage capacity available in the United States, it should be apparent that industry has the utmost confidence in the containment and security of this concept.

Solution Mined Cavern Risk Areas

Early brine caverns were used to provide feedstock for chemical plants. With continued use, some of these caverns were allowed to coalesce with adjacent caverns or were allowed to wash upward, destroying the rock salt roof. In some instances, the collapse of a large cavern at shallow depth resulted in the formation of a large "sinkhole." These problems have been eliminated in more recent caverns by careful attention to the solutioning process and judicious use of blanket material and sonar surveys.

The first high-pressure natural gas storage caverns were solution mined at a depth interval of 5,700-6,700 feet. These caverns were operated "dry" between predetermined maximum and minimum pressures. During operation, it was noticed that the cavern tended to shrink or suffer "closure" because of the plastic nature of the rock salt at the minimum pressure and strata temperature. These caverns were subsequently washed to design volume in the upper portion of the cavern, and more care was used in maintaining an elevated minimum pressure. Although these original caverns are still in use, subsequent gas storage caverns have been constructed at shallower depth intervals and have not experienced closure problems. Ironically, it is this same plastic nature of the salt that seals the high pressure gas so successfully.

All solution mined caverns have at least one access hole consisting of a steel pipe externally cemented to the salt formation and throughout its length to the surface. At least two LPG caverns are believed to have leaked at the casing seat or cement seal. One cavern was ordered plugged and abandoned by the state. The casing of the other cavern was reworked after which the cavern was returned to service. One factor that sometimes complicates the proper cementing of a casing string in a salt dome is the presence of void areas or "lost circulation zones" in the cap rock above the salt. Conservative designs utilize a surface casing string into the cap rock, an intermediate casing string into the top of the salt, and a final production string of casing set at least 300 feet into the salt. In this manner, the dual strings of casing into the salt provide protection from possible corrosion. Hazardous waste caverns constructed in salt domes should have dual casing strings into the salt for maximum integrity, but their risk period will end when the cavern becomes full of waste and the access hole is plugged by cementing it throughout its length.

The only remaining risks would then be earthquake or inadvertent drilling into the cavern. If these risks are unacceptable, the waste may be solidified in-situ by mixing with some solidifying ingredient such as cement or a polymer.

SECTION 5

THE SOLUTION MINING PROCESS

Historical Development of Solution Mining Concepts

From the 1880s, when some of the first solution mining methods and equipment were patented, until the 1950s, solutioning efforts were aimed primarily at brine production. The commercial value of caverns, which remained after removal of large volumes of salt, was not initially recognized. However, since 1950, many caverns created as by-products of brine production have been converted to storage of hydrocarbons, and many new caverns are being constructed specifically for storage.

Prior to the 1930s, brine was produced from a single well drilled into a salt deposit. Piping in the well was arranged either side-by-side or concentrically. Water was introduced through the feed pipe set near the top of the deposit, and the resulting brine was removed through a second pipe set near the bottom of the cavity being formed. Brine was either mechanically pumped to the surface or forced out of the cavity under pressure supplied by a fresh water injection system.

An important advance in solution mining technology occurred in the 1930s. This was the practice of inserting an air "blanket" at the top of the developing cavern, thereby limiting upward growth. Using this technique, much greater lateral growth could be achieved before communication with the next highest salt layer caused caving of the interbedded shale layer resulting in well difficulties.

In the 1950s, attention was focused not only on brine production, but also on the solution mining of caverns suitable for storage of hydrocarbon liquids and gases. Liquid hydrocarbon blanket materials were introduced, and the level of blanket material in the cavity and the position of tubing strings were adjusted during washing to influence cavity shape and size.

Introduction of the sonar survey also represented an important advance in subsurface engineering. The survey tool, an acoustical device, can be lowered into the cavern to take measurements that are then used to plot cavern shape and calculate cavern volume.

Basic Requirements for Solution Mined Storage Caverns

Three basic conditions must exist at the location where storage facilities are needed if solution mining is to be used for cavern construction:

- o A sufficient thickness of structurally competent salt at a proper depth, without an excess of interbedded insolubles, must be present.
- o An adequate supply of raw water for washing the salt must be available.
- o An environmentally acceptable and economical means of disposing of the resultant brine must be available.

Raw Water Supply

Raw water for solution mining is usually obtained from streams, rivers, lakes, or oceans if possible. In locations where surface water is not available, it is necessary to drill and complete high capacity water wells into shallow fresh or saline aquifers. It may even be necessary to use a municipal water supply.

Brine Disposal

The most desirable method of disposing of brine from cavern construction would be the use of the brine for chemical feedstock by an established chemical company. Where possible, this concept makes the best use of the basic resource and works to the advantage of both the chemical company and the storage developer. In actual practice, however, there are so many problems over the brine flow rate, saturation, and consistency of flow rate that this concept is seldom used.

Brine disposal into the ocean may be possible at some sites. The LOOP project near New Orleans, Louisiana pumped brine from cavern construction through a 30 inch pipeline approximately 28 miles to the coast and about 2 miles into the Gulf for disposal through a series of diffusers at a depth of about 20 feet.

Most solution mined storage facilities use deep disposal wells for brine from cavern construction. Disposal wells serving Gulf Coast salt dome caverns are usually located about one mile or more off the flank of the dome. These wells are generally drilled to depths of 5,000 to 7,000 feet and a geophysical logging and coring program is used to identify acceptable disposal formations.

Unfortunately, deep disposal is not an easy operation in the Northeastern United States. Even deep wells offer only relatively tight rock formations, resulting in low disposal rates per well. This increases facility cost (due to the larger number of disposal wells required), and makes operating costs higher (due to the higher pressures involved and the need for filtration to avoid formation plugging).

Salt Dome Solution Mining Techniques

A variety of cavern configurations can be constructed in salt domes. The rate of washing, overall washing time, casing positions, degree of blanket level control, percent of insolubles in the salt stock, solubility of the salt stock, and space limitations with respect to adjacent caverns or the edge of the dome all are factors which can influence cavern shape.

The fundamental technique of salt dome cavern development is to drill into a salt mass and to pump "raw" (fresh or low salinity) water into the hole, thus dissolving the salt, which is then carried to the surface as a brine solution. The hole within the exposed salt gradually enlarges, eventually forming a useful cavern. In actual practice, the procedure for cavern development is somewhat more complex. A typical storage well configuration is shown in Figure 1.

Some insoluble material, such as anhydrite, is present in most dome salt. As washing proceeds, an accumulation of insoluble material builds up in the bottom of the cavern, which may cause plugging of the wash casing or inhibit free circulation. If this occurs, it may be necessary to raise the wash casing to a new position before continuing.

The problem of insoluble accumulation may be minimized by constructing a sump below the cavern interval to collect the rubble. This sump is washed below the storage interval before cavern washing begins. The size of the sump depends upon the amount of insolubles estimated to be produced. The estimate is based on core samples taken during initial well drilling operations.

A modern technique for washing caverns yields an approximately cylindrical shape. This procedure minimizes the number of pipe movements required, while maximizing the salinity of the produced brine to reduce the construction schedule.

The sump is developed first. The well bore extends to the bottom of the predetermined sump interval. Wash casing is set near the bottom of the well bore and blanket casing is set slightly below the product casing seat. Blanket material is then injected into the annulus between the blanket casing and the product casing as shown in Figure 2.

Blanket material can be any substance that is lighter than water, immiscible with water or brine, and that does not dissolve salt, e.g., propane, butane, diesel oil, crude oil. Consequently, the blanket occupies the space in the topmost interval of the cavern. Its primary purpose is to prohibit dissolving salt from around the final cemented casing. It also protects the product casing from internal corrosion and can be used to initially depress washing to the bottom of the borehole. The protective blanket is extremely important, requiring careful monitoring and maintenance. Protection of the cemented casing serves the dual purpose of insuring a pressure-tight cavern and prohibiting development of high spots in the cavern roof.

Direct circulation (fresh water injected near bottom of cavern) is used to develop the sump with a teardrop shape. During, this period, insolubles in the salt will be carried to the surface by the relatively high fluid velocity. Separators and settling tanks may be used to remove most of the sand-like material. The fine anhydritic sand is taken by truck to an acceptable landfill area for disposal. The clean brine is injected into a brine disposal well.

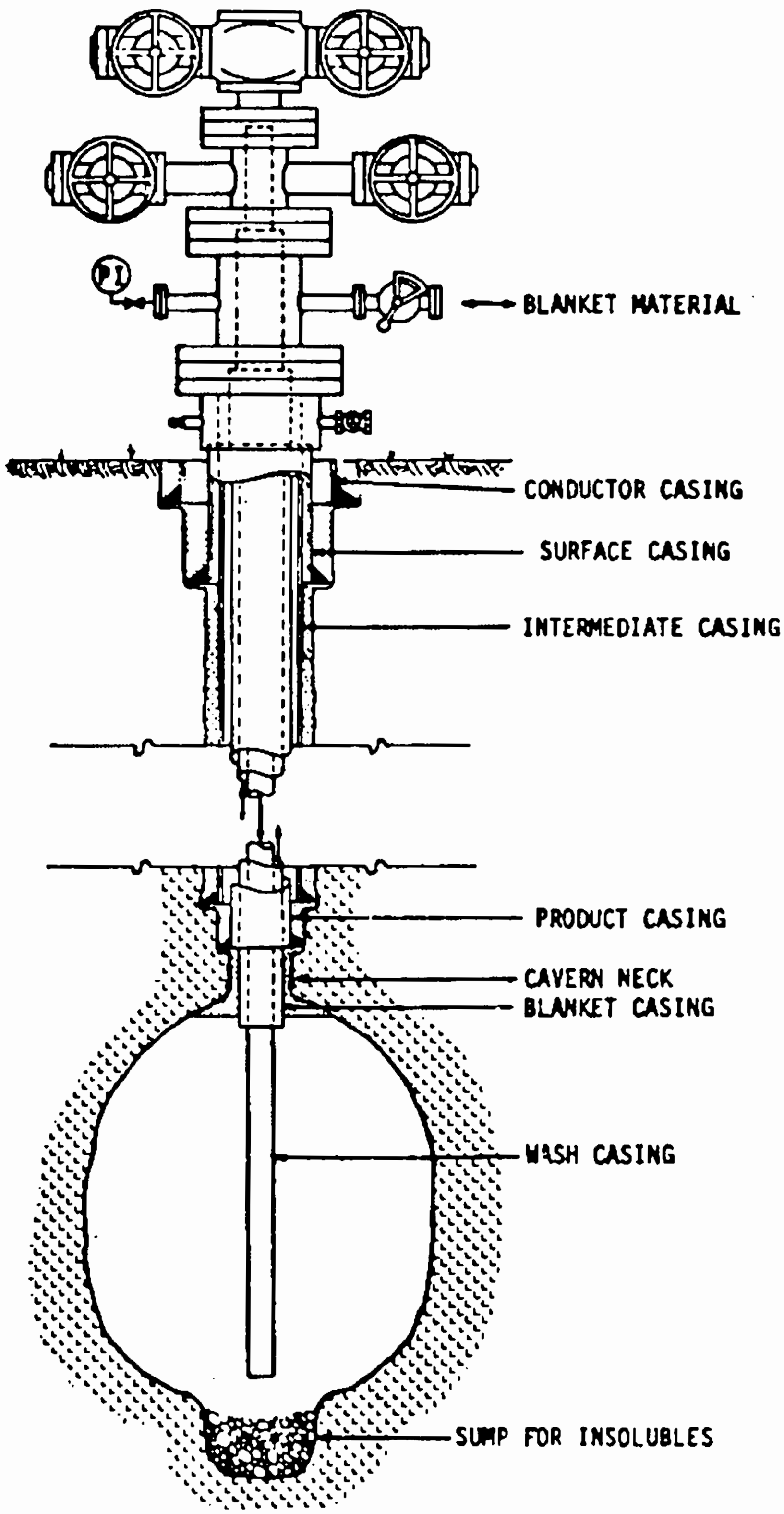

Figure 1 Typical Salt Dome Storage Well Configuration

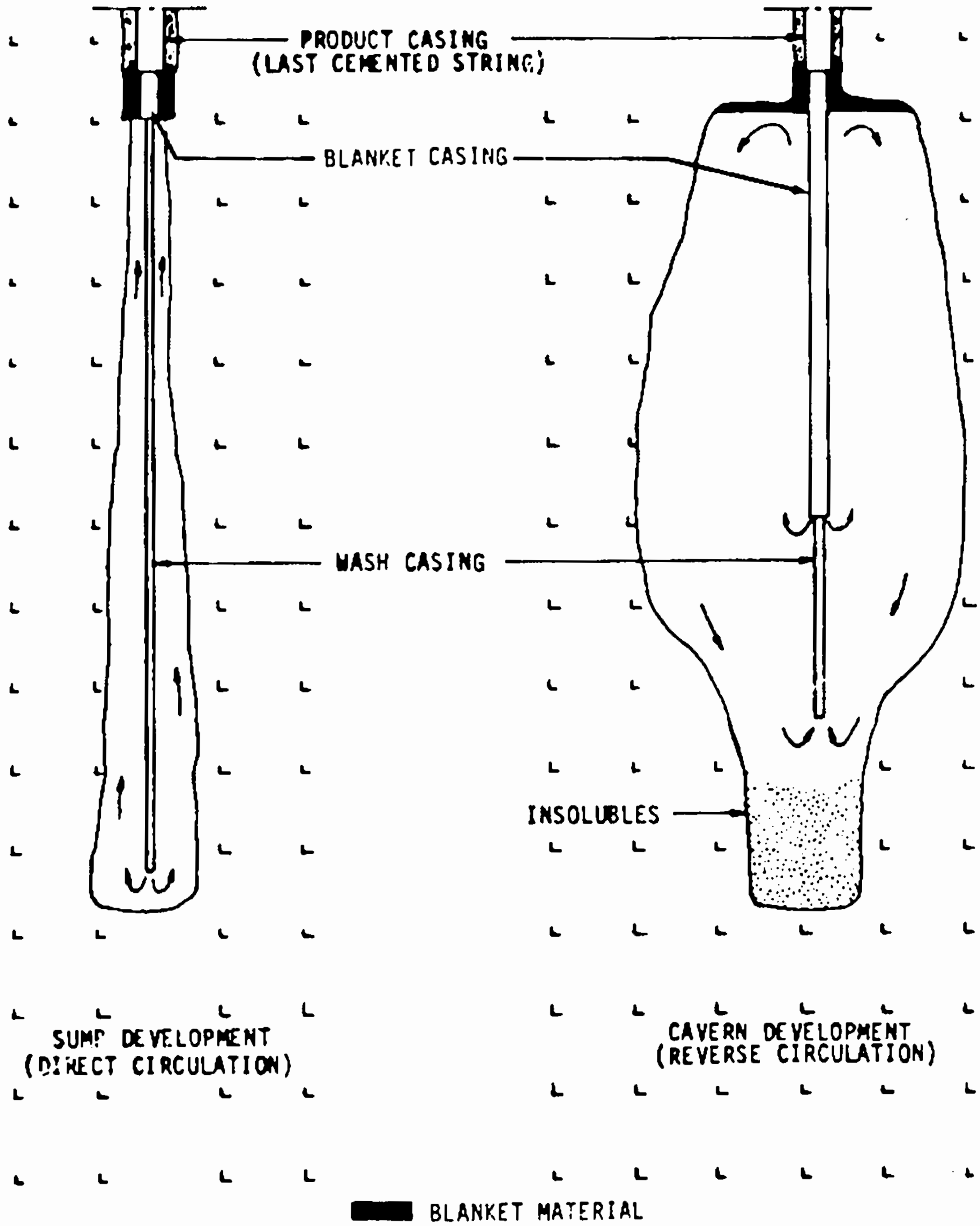

Figure 2 Salt Dome Cavern Washing

After the sump has been washed to the proper configuration, the blanket material is removed to storage, a rig is moved in, and the wash casing and blanket casing are repositioned after which the blanket material is again installed. The cavern is then developed by reverse circulation (introducing fresh water into the annulus between the wash casing and blanket casing and withdrawing saturated brine from the lower cavern area through the wash casing). As cavern volume increases, fluid velocity in the cavern decreases and residence time increases, allowing the brine to become saturated and permitting most of the insolubles to settle into the sump provided.

Bedded Salt Solution Mining Techniques

The basic principles of solution mining such as the use of blanket material, direct and indirect circulation, etc. are the same in bedded salt as in a salt dome. Bedded salt, however, presents additional problems due to lack of thickness of the salt resource and also due to the tendency of large interbedded shale layers to collapse and damage the suspended casing strings. In general, the bedded salt insolubles tend to fall to the bottom of the cavern as a pile of large rocks, rather than as fine sand as is the case in a dome cavern. A common problem with bedded caverns occurs if the brine string is removed for repair or replacement only to find that it cannot be reinstalled to its former depth because of striking a shale ledge or a repositioned pile of rocks. Due to the shallow nature of most bedded salt formations, it is usually not possible to provide a sump as shown for the salt dome caverns. Instead, the entire lower portion of the cavern acts as a sump. It is also difficult to develop high salinity brine at high rates in a bedded salt cavern unless multiple wells are used.

Multiple wells are common in existing bedded salt caverns because they were developed to produce high salinity brine rather than storage. Many of these caverns were created by fracturing the formation from one solution well to another. It is usually impossible to define the configuration of "sausage-type" caverns and high spots may make them unsuitable for the storage of hazardous waste.

If proper procedures are used, it is possible to create relatively small, but secure caverns in bedded salt.

Solution Mine Facility Design and Construction

The storage well is the key and most expensive component of the system, requiring considerable planning, design, and technically qualified geological and engineering supervision during drilling operations. Raw (fresh) water, acquired from wells or surface sources, is stored in tanks designed to provide adequate suction conditions. The water is pumped to the storage wellhead and down suspended casing strings to dissolve the salt and create the storage space. The piping systems, the blanket system, the insolubles removal system, and the brine disposal system are designed to accommodate the desired rate of construction. Figure 3 shows the major equipment components for cavern construction.

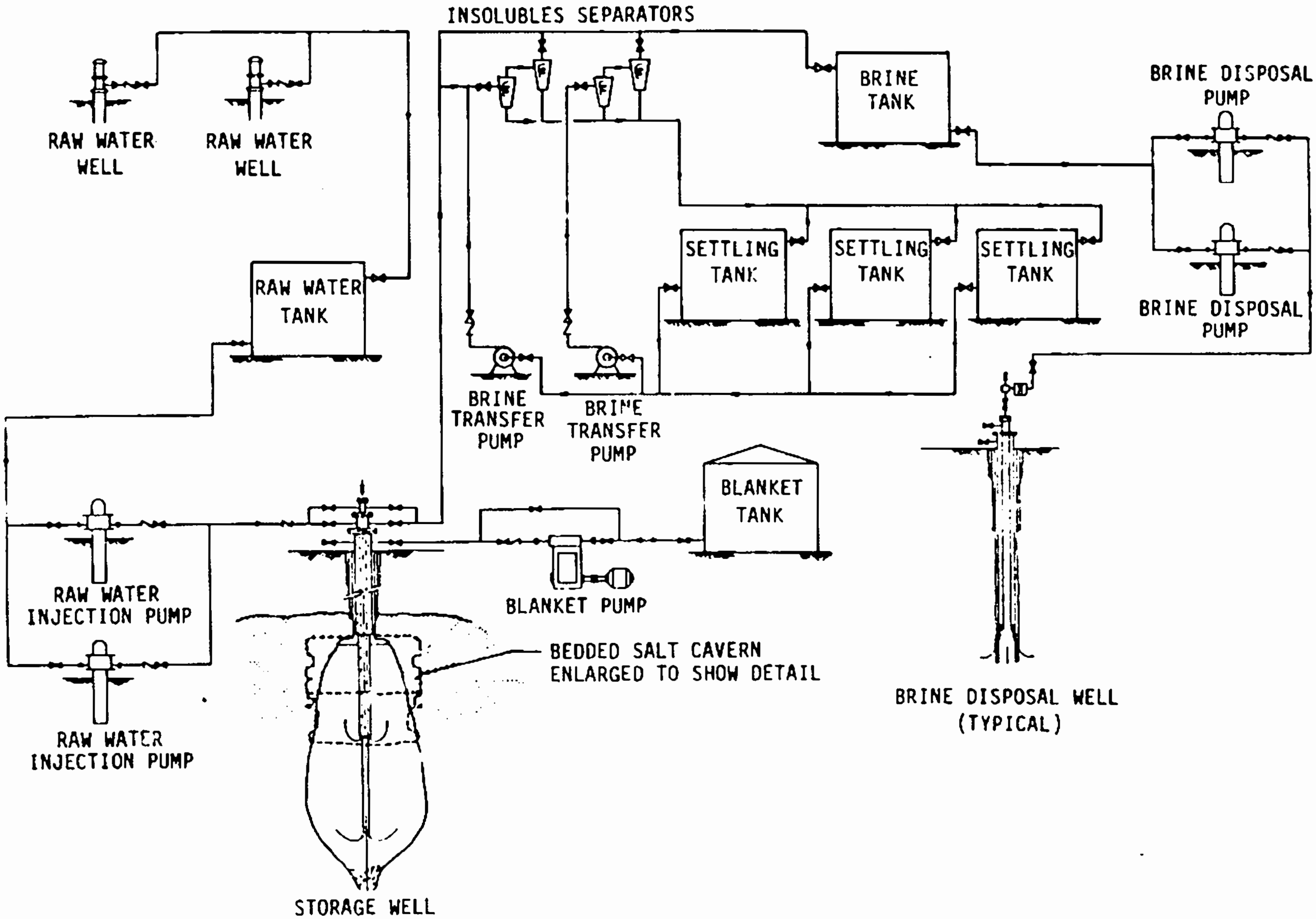

Figure 3 Conceptual Flow Diagram for Construction of Hazardous Waste Retention Cavern in Salt

SECTION 6

ADVANTAGES OF SOLUTION MINED STORAGE

Solution mined caverns may provide containment for hazardous wastes and isolation of those wastes from the environment. After the hazardous waste has been mixed with a cement or polymer slurry, injected into a solution mined cavern, and allowed time to solidify in-situ, the plastic nature of the salt under strata pressure will seal the wastes.

Large salt deposits in the U.S. are located near a number of the major hazardous waste generation areas, minimizing transportation and handling costs. This may be one of the most economical methods of providing permanent retention of hazardous waste.

SECTION 7

SALT GEOLOGY OF THE UNITED STATES

Large deposits of salt exist in many areas of the world and are usually found lying between beds of shale, anhydrite, gypsum, or limestone. Salt is an evaporite, an accumulation of crystals precipitated from impounded sea water in an arid environment. The principal salt deposits within the United States are shown in Figure 4. Many of these salt deposits have been utilized for the construction of underground solution mined caverns in which products such as natural gas, hydrogen, propane, butane, ethylene, gasoline, and other hydrocarbon fuels have been stored.

Bedded Salt

Most salt deposits in the United States are of the bedded salt type. From the standpoint of storage, the largest bedded salt deposits are the Salina Basin ranging from Michigan to Western New York and the Permian Basin extending from West Texas and Eastern New Mexico to Western Kansas.

Many salt companies have conventionally mined and solution mined the bedded salt in Northeastern Ohio and in the Detroit and St. Clair areas of Michigan. The salt in these areas is of a substantial thickness and lies at a relatively shallow depth, close to large population centers. Thus, these areas have been economically attractive for the production of rock salt for table use and for saturated salt brine for chemical plant feedstock. Also contributing to the success of solution mining in these areas has been the abundant supply of fresh water for solutioning.

Bedded salt does impose limitations on cavern design and operation due to the presence of interbedded stringers of shale or mudstone. As a general example of bedded salt in northeastern Ohio, the Salina salt bed distribution and thickness is shown in Figure 5. Contours showing the depth to the top of the salt in northeastern Ohio are shown in Figure 6. A composite section showing the various salt formations and the shale interbedding in northeastern Ohio is shown in Figure 7.

Salt Domes

The bedded salt shown in the Gulf Coastal regions of Texas, Louisiana, and Mississippi is buried so deep that it has not been penetrated with a drill bit. Based on the depth of its northern fringe, its rate of dip to the south, and the thickness of upper sediments, geologists postulate that the bottom of the strata, known as the Louann Salt, is more than 30,000 feet below the earth's surface. It is from this bed that salt domes are born.

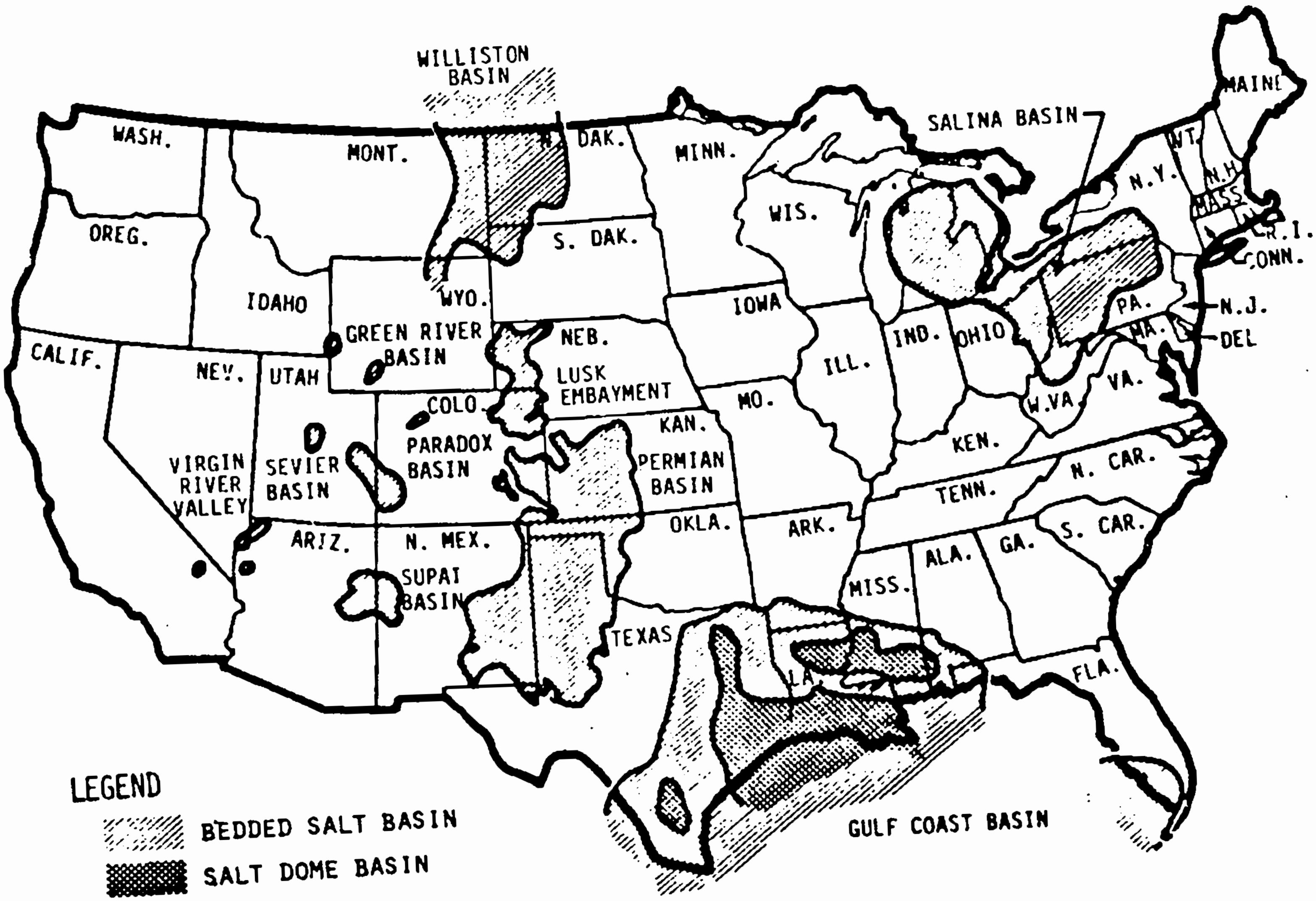

Figure 4 Principal Salt Deposits Within the United States

SOURCE: Silurian Rock Salt of Ohio Report of Investigation No. 90, M.J. Clifford, State of Ohio Dept. of Natural Resources, 1973.

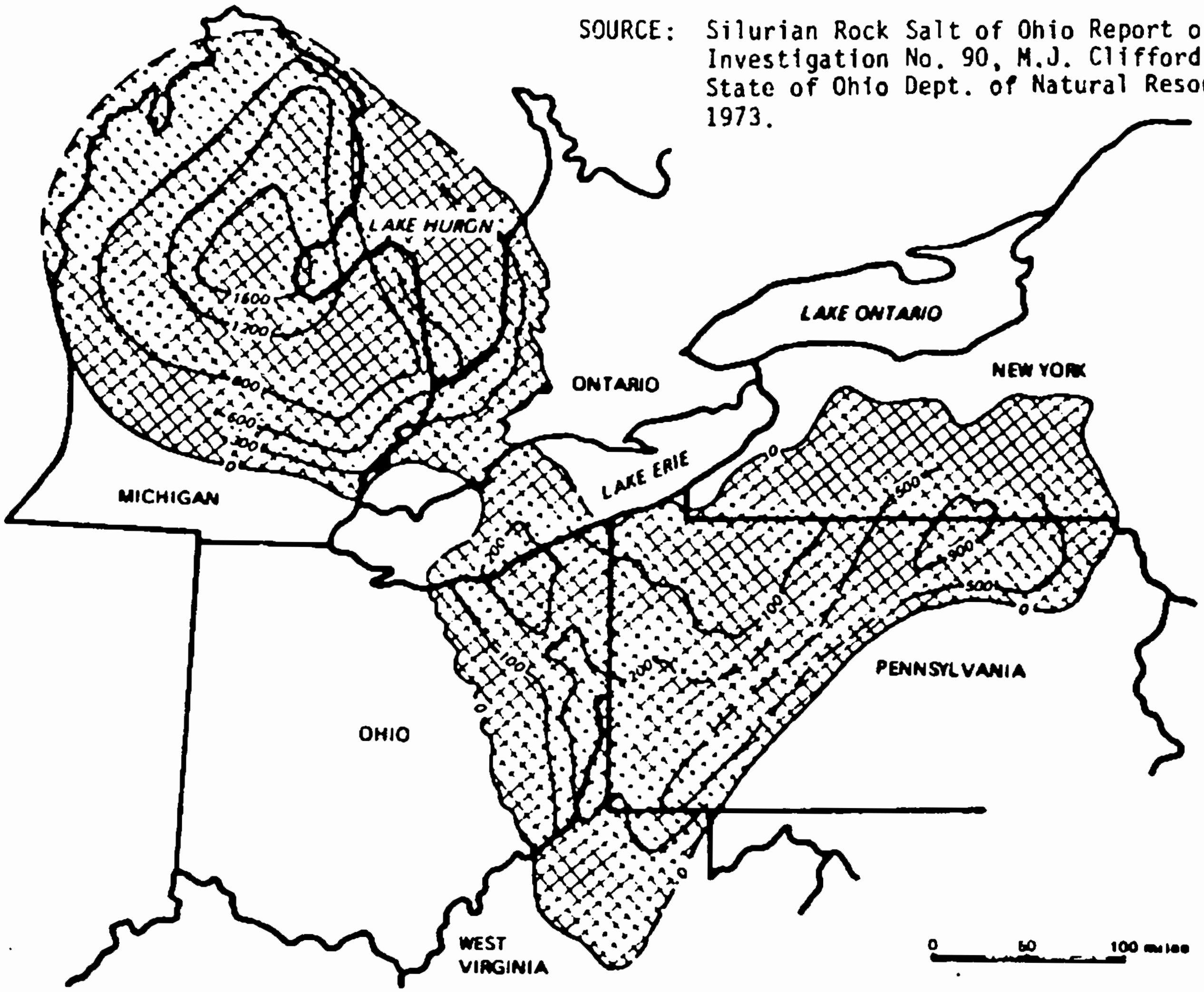

Figure 5 General Distribution and Thickness of Salina Salt Beds

SOURCE: Silurian Rock Salt of Ohio
Report of Investigation No.90
M.J. Clifford, State of Ohio
Dept. of Natural Resources, 1973.

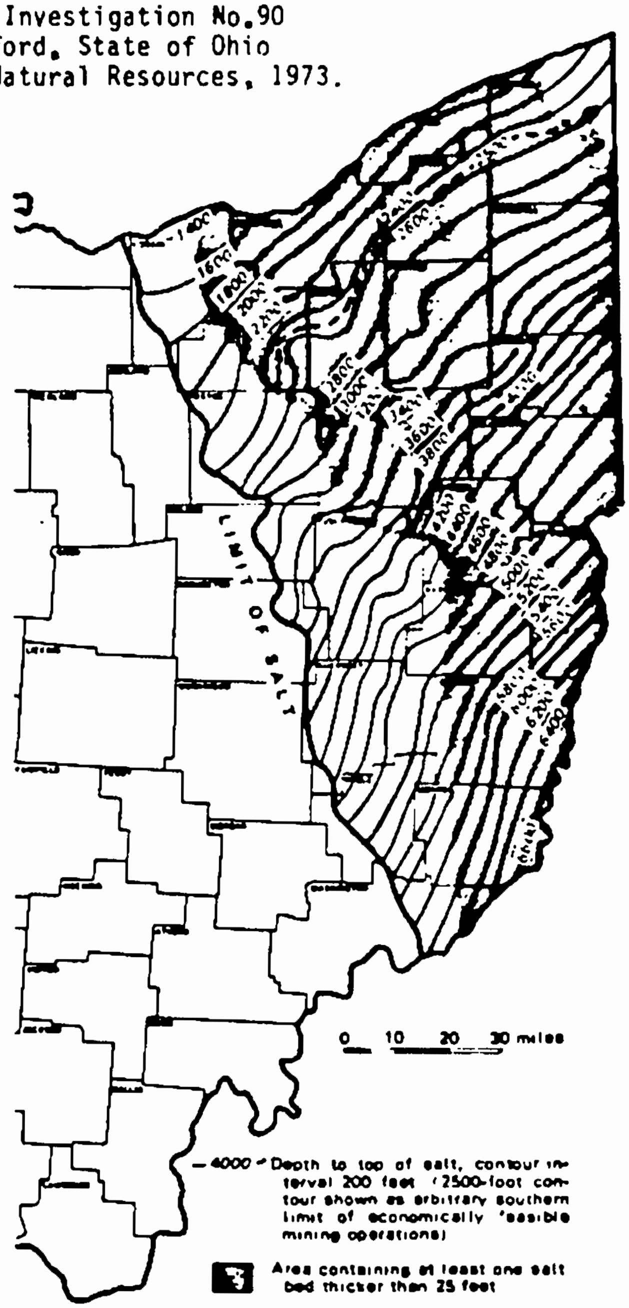

Figure 6 Depth to Top of Salt in Northeastern Ohio

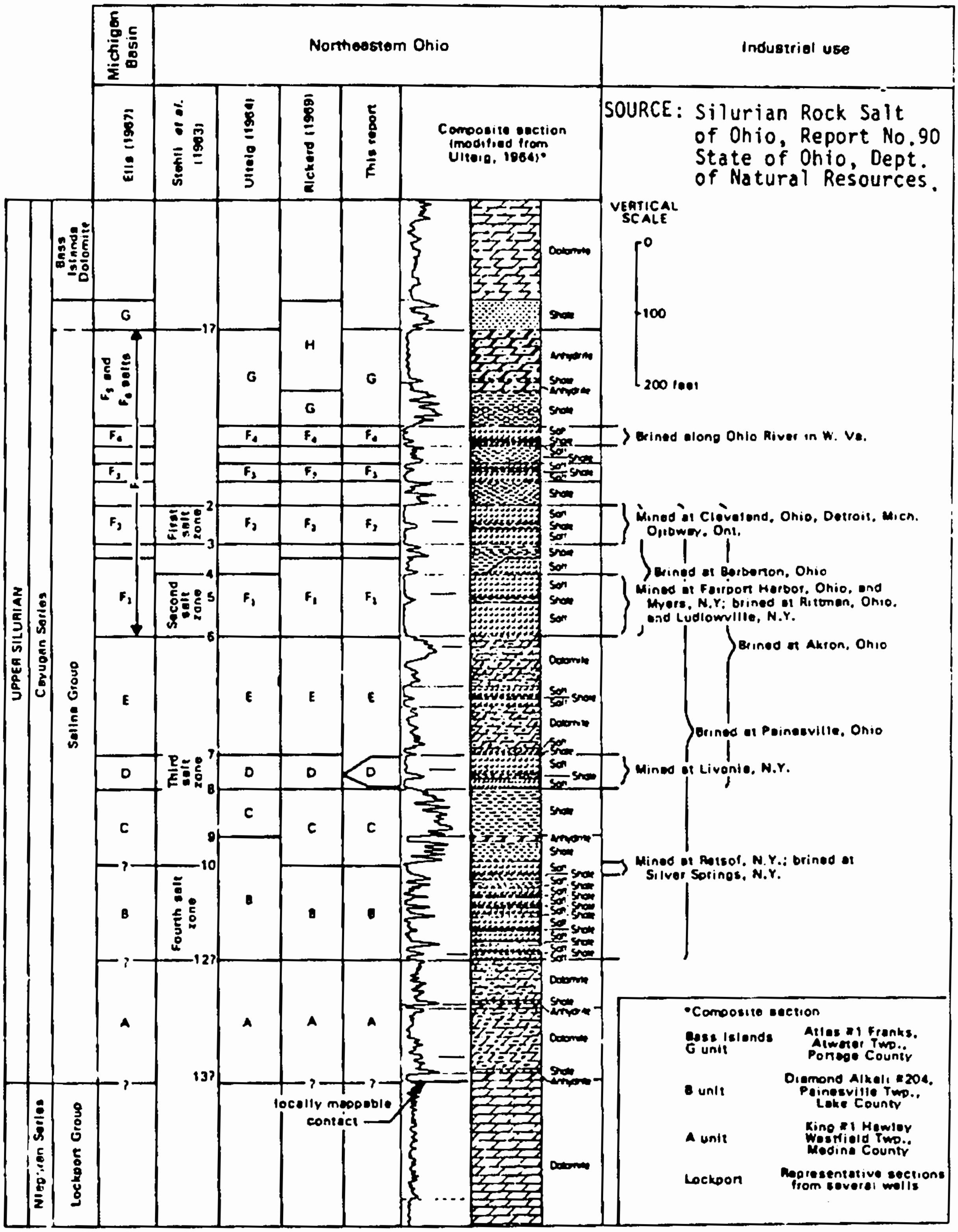

Figure 7 Composite Section Showing Salina Salt in Northeastern Ohio

Salt domes are relatively narrow stems of salt extending upward from great depth; in some instances they penetrate the surface. It is not known how many domes actually exist, for undoubtedly many terminate at such great depth that their presence is undetectable. However, over 520 have been discovered in the U.S., and many are close enough to the surface to be potential candidates for storage sites.

Subjected to extremely high temperatures and tremendous pressure from overlying sediments, the behavior of the Louann bed is similar to that of a very fluid plastic. This fluid condition at the base of the dome gradually changes to a very hard plastic at its summit. When relieved of significant overburden pressure, as when a core is brought to surface, the salt becomes very brittle and often displays a coarse crystalline structure.

Salt is generally impervious to and insoluble in liquid or gaseous hydrocarbons, has a compressive strength comparable to concrete, and can be easily mined by dissolution in water. This unique combination of characteristics makes salt an ideal rock for cavern construction.

It is the hard plastic characteristic of salt at cavern depth that enables it to become an excellent high pressure storage vessel. Its ability to yield and divert stress from the cavern wall minimizes the stress concentrations that cause spalling or caving. Salt's plasticity also allows it to close and seal fractures. One Mississippi salt dome cavern was used to contain a nuclear explosion equivalent to approximately 300 tons of TNT. The cavern was later subjected to two other methane-oxygen explosions, each equivalent to about 300 tons of TNT. Following the third explosion the cavern was pressure tested and determined to be without leakage.

A great deal of effort, time, and money has been expended in the search for salt domes. Of course, the earliest efforts were directed toward locating domes that reached, or nearly reached the surface so that the salt could be mined.

The petroleum industry has conducted by far the most intensive salt dome exploration effort. Here, the motivation has been a search for oil traps. Whether sedimentary beds have been tilted upward by the rising plug of salt or tilted downward by the weight of accumulating sediment has been a geologic riddle. There can be no doubt, however, that the resultant distortion of formations frequently produces entrapment zones for accumulations of oil and/or gas.

In later years, salt has also been recovered from deeper domes by sc . tion mining, primarily to provide saturated brine as feedstock to the chemical industry.

Figure 8 shows the known Gulf Coast salt domes. Some of these domes would not be suitable for hazardous waste storage because extensive hydrocarbon storage facilities have already been installed, but some could be utilized for this purpose.

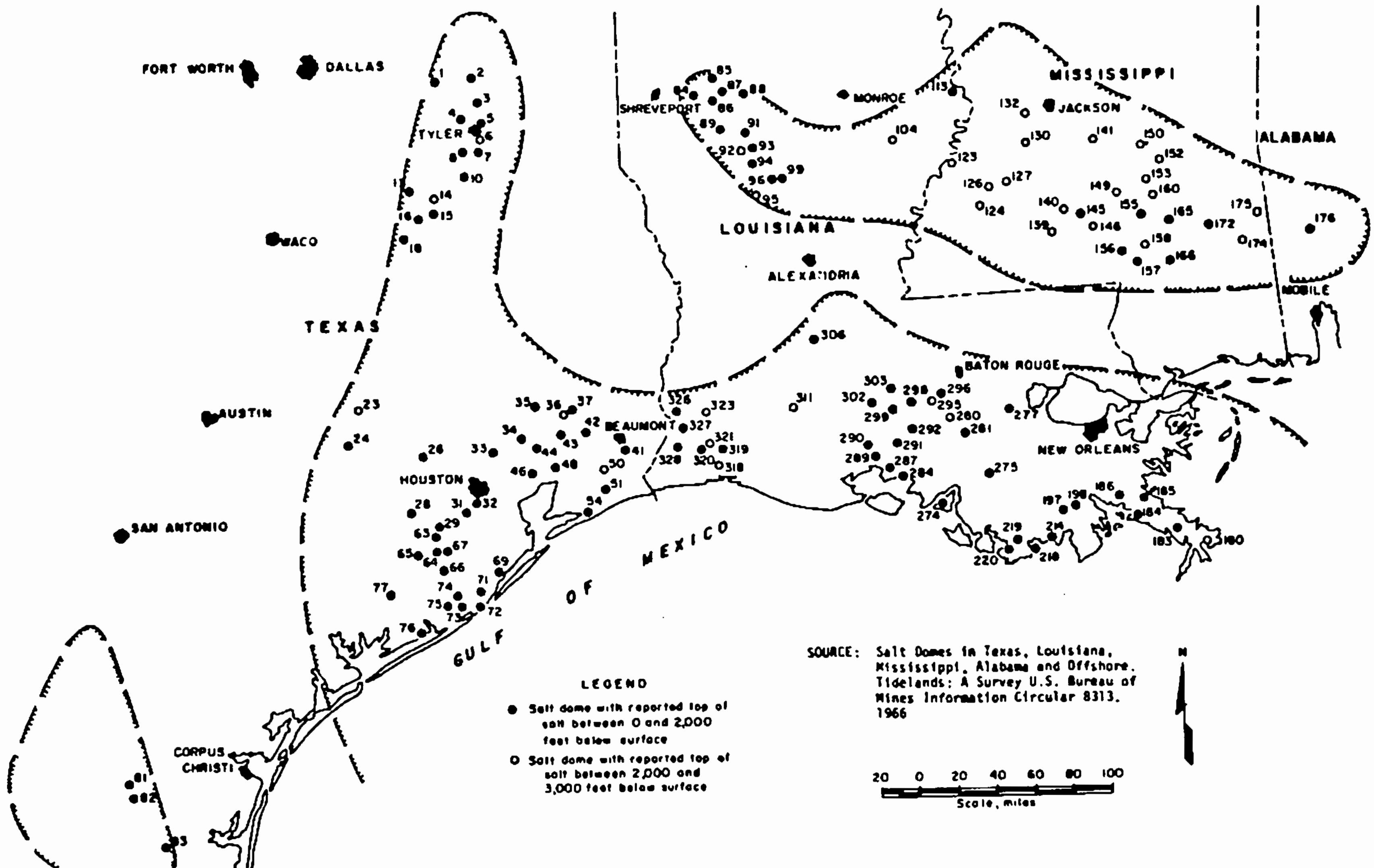

Figure 8. Map of Gulf Coast Salt Domes

A generalized cross-section of a typical Gulf Coast salt dome is shown in Figure 9.

Salt dome cap rocks also have been the object of considerable commercial interest. In fact, much of the drilling performed over domes has been conducted to evaluate possibilities for sulfur recovery from the cap rock.

The origin of cap rocks, like the origin of salt domes, remains a subject of dispute among geologists. However, most investigators now seem to agree that cap rock represents an accumulation of insoluble material originally transported within the salt. Presumably, as the salt moved upward relative to the surface of the earth, its upper face was continually dissolved by unsaturated brines lying above. As the salt dissolved, gypsum, sulfur, and other minerals may have evolved as the products of altered anhydrite.

As the cap rock gained in thickness and maturity it suffered from the dissolving action of shallow saline waters. Numerous voids are usually found in cap rocks, and occasionally a drilling bit will drop through what appears to be a large cavern. Perhaps as a result of the weaknesses caused by natural dissolving, most cap rocks are highly fractured.

A typical Gulf Coast salt dome which could be used for the retention of hazardous waste is the Vinton Dome in Calcasieu Parish, Louisiana (refer to Figure 10). The depth to the top of the cap rock is about 720 feet, and the depth to the top of the salt is approximately 1,130 feet. Fresh water for solution mining could be obtained from the Vinton Canal or from water wells. Brine injection into deep disposal wells has been used extensively in the past for cavern development and should present no problem.

Seismic Risk

Many of the prime salt deposits suitable for hazardous waste storage lie outside of the main seismic risk areas of the United States as shown in Figure 11. However, during the site selection process for hazardous waste caverns, due consideration must be given to the possibility of earthquake damage.

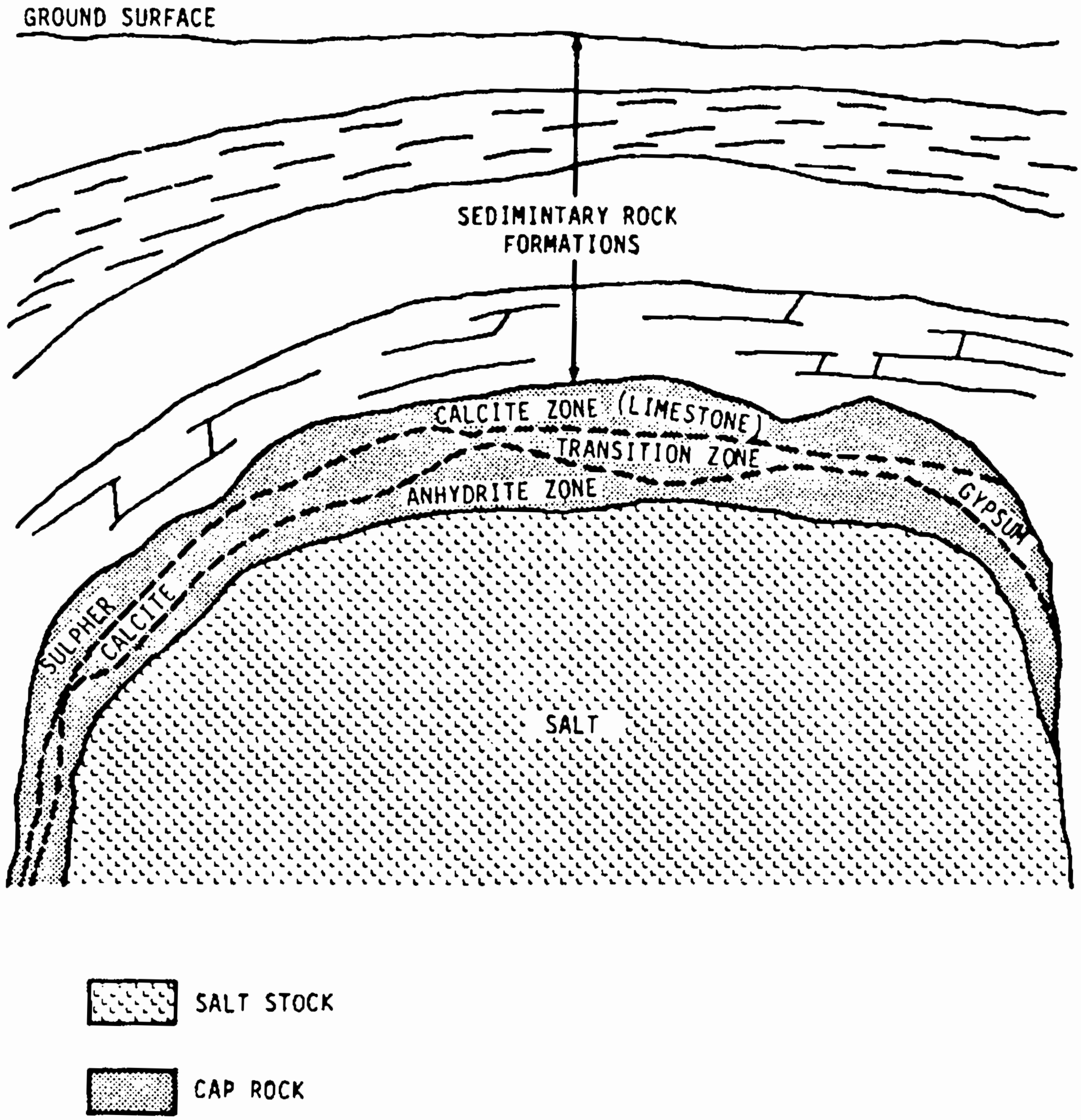

Figure 9 Generalized Geologic Cross-Section of a Gulf Coast Salt Dome

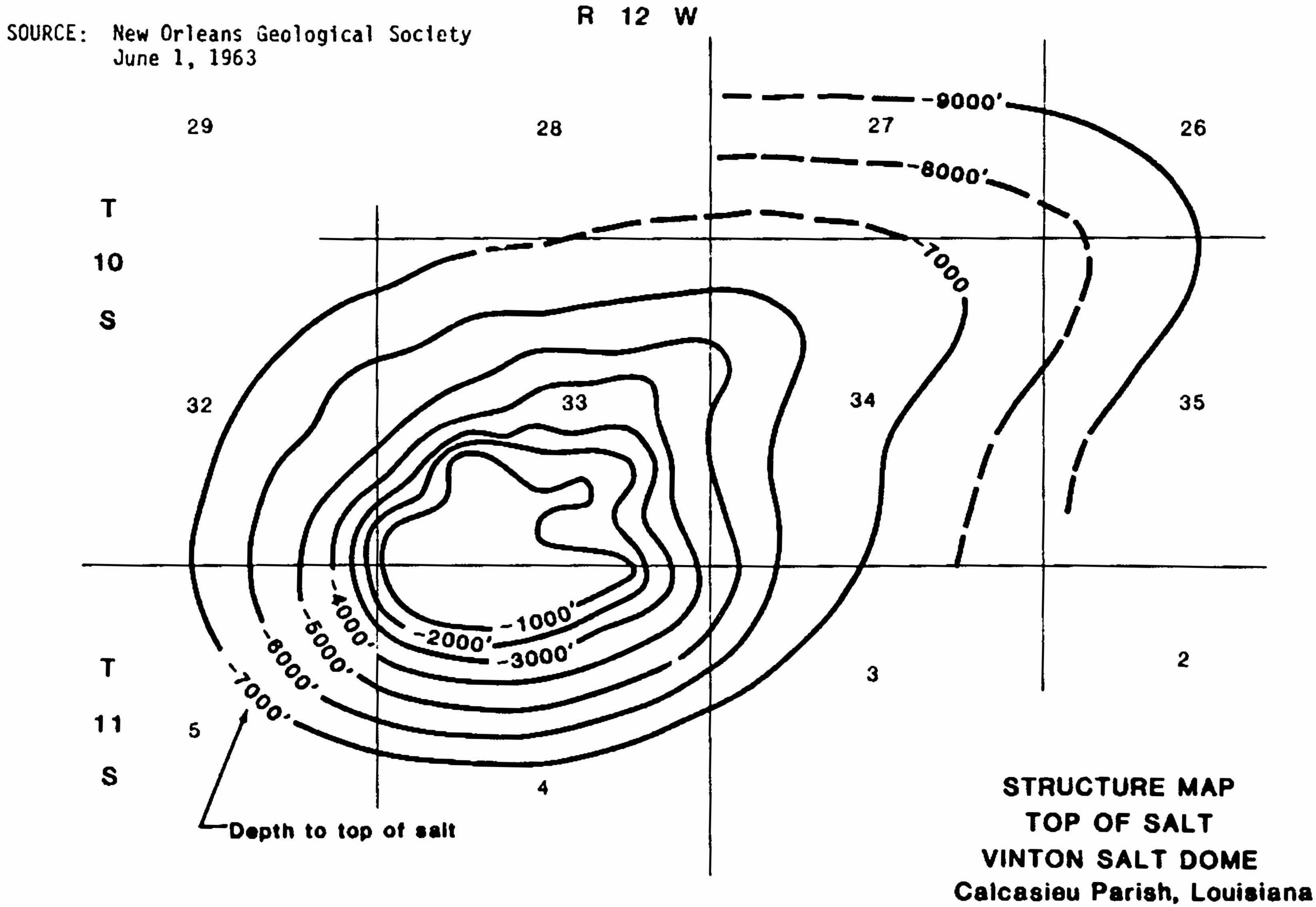

Figure 10 Structure Map of Vinton Salt Dome, Louisiana

*(from Earthquake History of the U.S.-Publication 41-1, NOAA)

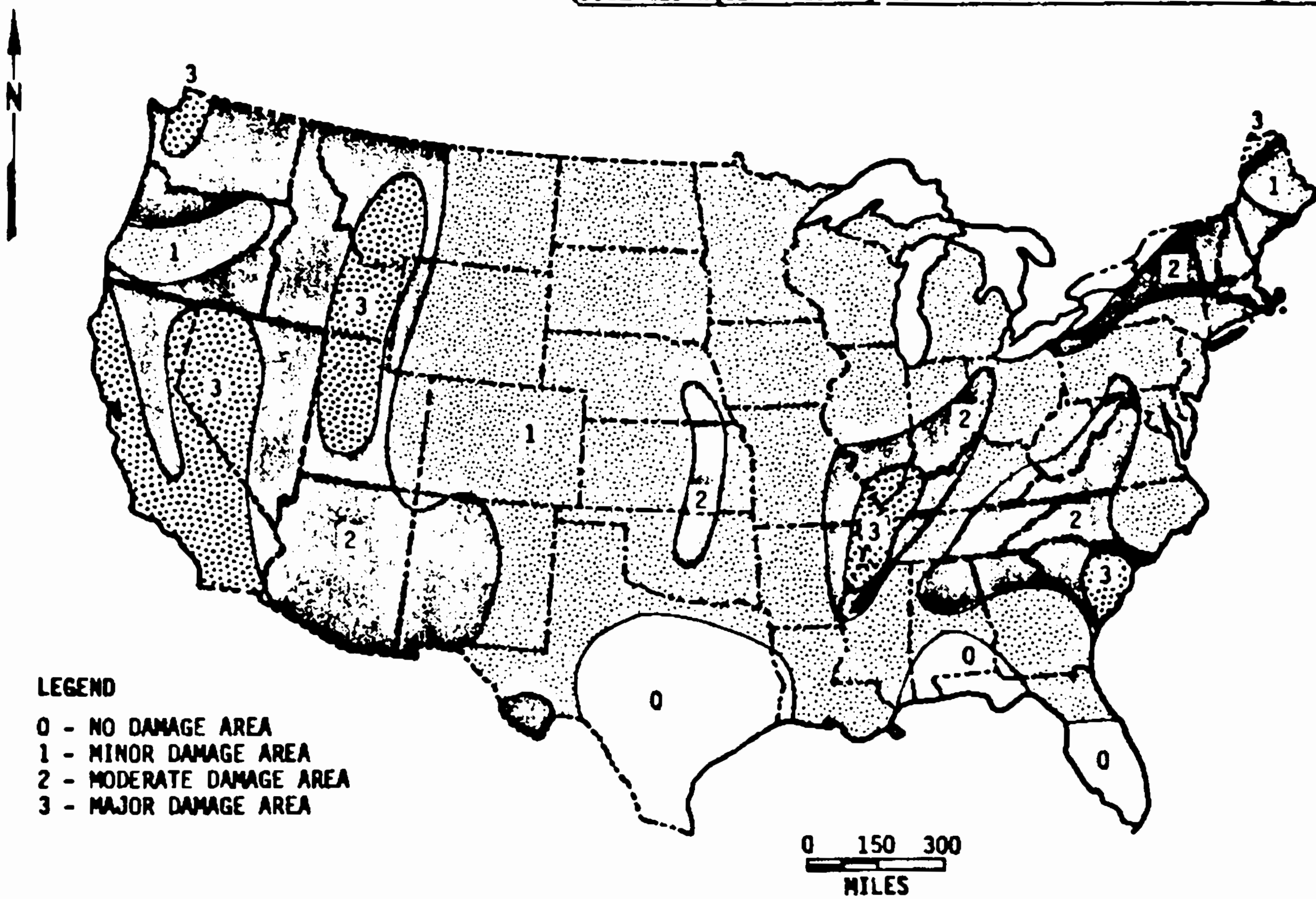

Figure 11 Seismic Risk Map of the United States

SECTION 8

WASTE GENERATION BY EPA REGION VS. SALT DEPOSITS

Of the ten EPA regions, the four largest producers of hazardous waste are III, IV, V, and VI as shown in Figure 12. In 1980 these four regions produced 78 percent of the nationwide total as shown in Table 1.

Regions IV and VI, with 25 percent and 26 percent of the Nation's hazardous waste, respectively, both have salt domes with adequate volume.

Regions III and V, with 11 percent and 16 percent of the Nation's hazardous waste, respectively, both have bedded salt caverns which could be utilized. Although these caverns would be smaller and more numerous for the same volume of storage in comparison with dome salt caverns, shipping costs would be reduced and they might be cost effective on an installed cost pe. barrel basis, if brine disposal wells can be developed.

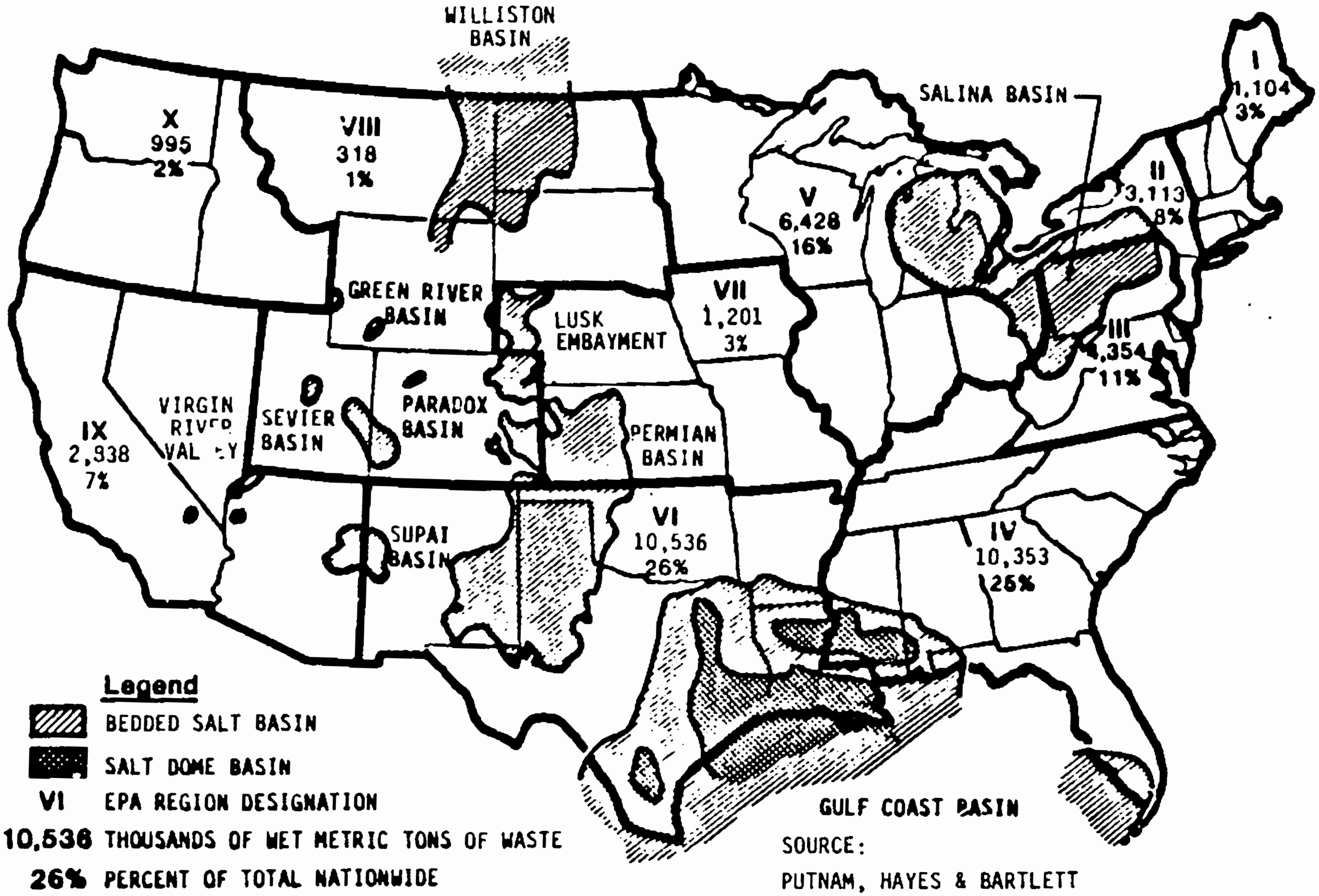

Figure 12 1980 Hazardous Waste Regions Vs. Salt Deposits

REGION	1980			1981			
	TOTAL	OFFSITE	UNKNOWN	TOTAL	OFFSITE	UNKNOWN	MOST PROBABLE
I	1,104	299	368	1,131	303	385	580
II	3,113	652	540	3,216	673	564	1,022
III	4,354	604	470	4,507	622	492	922
IV	10,353	913	674	10,697	940	706	1,358
V	6,428	1,330	1,537	6,611	1,368	1,604	2,517
VI	10,536	1,029	524	11,025	1,059	549	1,346
VII	1,201	252	233	1,231	257	243	440
VIII	318	106	61	325	108	62	154
IX	2,838	535	511	2,925	552	534	896
X	995	348	241	1,023	357	249	503
TOTAL	41,235	6,069	5,159	42,694	6,251	5,395	9,738

NOTE: DETAIL MAY NOT ADD TO TOTAL BECAUSE OF ROUNDING.

SOURCE: PUTNAM, HAYES & BARTLETT

Table 1 1980 and 1981 Industrial Hazardous Waste Generation and Most Probable Off-Site Disposal, by EPA Region (Thousand Wet Metric Tons)

SECTION 9

SALT CHEMISTRY

When referring to the naturally occurring substance, either the term "rock salt" or the mineral name "halite" is used. Salt is never found absolutely pure, although the percentage of NaCl may run well over 98 percent. Most salt deposits have been formed by deposition from ocean water containing many other dissolved and suspended substances in addition to the salt.

Since hazardous wastes could potentially be stored in salt caverns in any location in the U.S., the chemical compatibility of the various hazardous wastes with the various salt compositions should be verified.

The most common insoluble impurities found in salt are anhydrite, dolomite, calcite, pyrite, quartz, and iron oxides.

The most common soluble impurities include the following ions: Ca, Mg, K, Cl, CO_3, and SO_4; in addition there may be Ba, Sr, B, and Br in minor amounts.

Sometimes the associated minerals constitute a significant part of a salt bed. Minerals commonly found in salt beds include the following:

Sylvite, KCl
Carnallite, $KMgCl_3.6H_2O$
Tachydrite, $2MgCl_2.CaCl_2.12H_2O$
Bischofite, $MgCl_2.6H_2O$
Kainite, $MgSO_4.KCl.3H_2O$
Anhydrite, $CaSO_4$
Gypsum, $CaSO_4.2H_2O$
Kiescrite, $MgSO_4.H_2O$
Epsomite, $MgSO_4.7H_2O$
Glauberite, $CaSO_4.Na_2SO_4$
Vanthoffite, $MgSO_4.3Na_2SO_4$
Glaserite, $K_3Na(SO_4)_2$
Langbeinite, $2MgSO_4.K_2SO_4$
Syngenite, $CaSO_4.K_2SO_4.H_2O$
Leonite, $MgSO_4.K_2SO_4.4H_2O$
Picromerite, $MgSO_4.K_2SO_4.6H_2O$
Bloedite, $MgSO_4.Na_2SO_4.4H_2O$
Loeweite, $MgSO_4.Na_2SO_4.2\text{-}1/2H_2O$
Polyhalite, $2CaSO_4.MgSO_4.K_2SO_4.2H_2O$
Krugite, $4CaSO_4.MgSO_4.K_2SO_4.2H_2O$

The following tables will illustrate the variation that is found in rock salt from different areas of the United States.

The three (1 in Table 2; 2 in Table 3) chemical analyses shown below are of rock salt from two domes on the Louisiana coast. They were taken from "The Five Islands, Louisiana" by Francis Edward Vaughan of Houston, Texas.

TABLE 2

ANALYSES OF SALT FROM AVERY ISLAND DOME

Chemist	NaCl	$CaSO_4$	$CaCl_2$	Mg_2Cl	$MgSO_4$	Other Matter	Not Determined
Jules Lafort	97.92	-	-	-	-	-	2.08
E. W. Hilgard	99.88	0.126	trace	-	-	-	-
Peter Colloer	98.90	0.838	0.146	0.022	-	0.080	0.014
Dr. Riddle	98.88	0.76	0.13	0.23	-	-	-
C. A. Goessman	98.88	0.79	trace	trace	-	0.33	-
C. A. Goessman	98.88	0.782	0.400	0.003	-	0.33	-
Joseph Jones	99.617	0.318	-	-	0.062	0.003	-
F. W. Taylor	98.71	1.192	trace	0.013	-	0.03	-
Dr. Doremus	99.097	0.729	-	-	0.158	0.039	-
Gustavus Bode	99.252	0.694	0.042	0.012	-	-	-

TABLE 3

ANALYSES OF LIGHT AND DARK SALT FROM BELLE ISLE DOME

	Dark Salt	Light Salt
Sodium Chloride	96.405	92.750
Calcium Sulphate (soluble)	3.051	-
Magnesium Chloride	.074	-
Magnesium Carbonate	-	2.01
Sodium Carbonate	-	.067
Sodium Sulphate	-	.836
Calcium Carbonate	-	1.804
Calcium Chloride	.226	-
Ferric and Aluminic Oxides (Fe_2O_3 and Al_2O_3)	.025	.500
Insoluble Matter	.059	3.325

Rock salt from New York, Ohio, Michigan, Kansas, and Texas has been chemically analyzed and the analyses are included herein as Tables 4, 5, 6, 7, and 8, respectively. These tables represent typical analyses reported by commercial salt mining companies.

TABLE 4

TYPICAL ANALYSIS OF ROCK SALT FROM NEW YORK

Sodium Chloride	98.28
Calcium Chloride	.02
Magnesium Chloride	.01
Calcium Sulphate	.48
Insolubles	1.21

TABLE 5

TYPICAL ANALYSIS OF ROCK SALT FROM OHIO

Sodium Chloride	98.14
Calcium Chloride	.01
Calcium Sulphate	.63
Magnesium Chloride	.04
Insolubles	1.18

TABLE 6

TYPICAL ANALYSIS OF ROCK SALT FROM MICHIGAN

Sodium Chloride	98.21
Calcium Chloride	.06
Calcium Sulphate	.65
Magnesium Chloride	.05
Insolubles	1.03

TABLE 7

TYPICAL ANALYSIS OF ROCK SALT FROM KANSAS

Sodium Chloride	94.22
Calcium Chloride	.02
Ferric Oxide	.02
Calcium Sulphate	3.24
Magnesium Chloride	.33
Insolubles	2.17

TABLE 8

TYPICAL ANALYSIS OF ROCK SALT FROM TEXAS

Sodium Chloride	89.80
Calcium Sulphate	5.50
Insolubles	4.70

SECTION 10

METHODS FOR STORING HAZARDOUS WASTE IN SOLUTION MINED SALT CAVERNS

There are a number of methods which might be employed for utilizing solution mined caverns for the storage of hazardous wastes.

Brine-Balanced Cavern with Brine Discharge During Waste Injection

Nearly all of the existing solution mined storage for liquid hydrocarbons in the U.S. is brine-balanced. The propane or crude oil, being lighter than brine, floats on top of it and flows under pressure when the product valve at the wellhead is opened. During product withdrawal, brine is added to the casing string hanging to the bottom of the cavern so that the cavern is maintained full of fluid at all times. When product is introduced into storage, it must be injected by means of a pump, displacing brine up the casing string and over to a brine holding pond. Caverns using this concept have a very long life because the range of stress on the salt is small.

The principal advantage if this method could be used for hazardous waste storage would be the possibility of utilizing very large caverns, perhaps comparable in size with the crude oil storage caverns of the Strategic Petroleum Reserve in Gulf Coast salt domes.

If the hazardous waste slurry were significantly lighter than saturated brine, the waste could be injected into the top of the cavern, displacing saturated brine up the casing string as shown in Figure 13. The displaced brine could then be injected into the same disposal wells that were used for construction of the cavern.

If the specific gravity of the waste were close to or greater than that of saturated brine, the waste slurry would have to be weighted so that it would be significantly heavier than the brine causing it to remain in the bottom of the other cavern as shown. The floating brine would be displaced from the top of this cavern and would be directed to disposal as before.

Although gravity segregation of liquids is used extensively in solution-mined caverns, the risk of contaminating the brine would increase as the specific gravity of the waste approaches that of the saturated brine. Brine contamination might also result from gases or vapors released by the hazardous waste in the cavern in the case of the heavy waste/floating brine cavern.

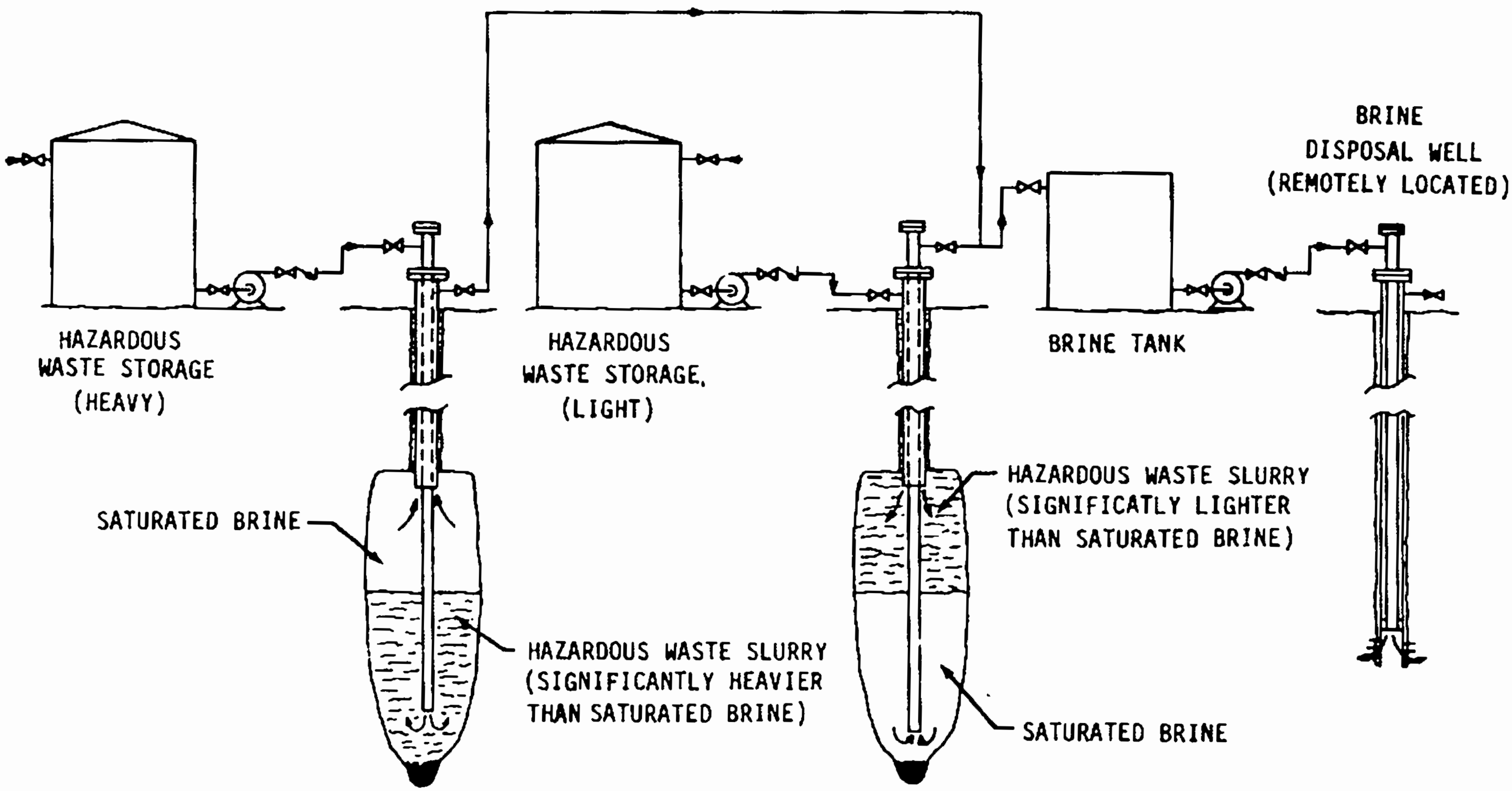

Figure 13 Brine-Balanced Cavern With Brine Discharge During Waste Injection

Gas-Balanced Cavern with Zero Discharge

In this method, after the cavern had been washed to capacity, the brine would be displaced by an inert gas and injected into a remote brine disposal well as shown in the cavern dewatering scheme of Figure 14. The cavern would be sealed at the minimum design pressure after which gaseous, liquid and slurry wastes would be injected into the cavern until the inert gas reached the maximum design pressure of the cavern as shown in the storage scheme of the same figure.

Gas-balancing might allow the use of a larger cavern than the atmospheric method, but smaller than the brine-balanced cavern. Gas-balancing also eliminates the possibility of contaminating the brine, and eliminates the need for a scrubber and flare, unless they were needed by the surface plant.

Atmospheric Cavern with Controlled Gas Discharge During Waste Injection

Following solutioning of the cavern to its design capacity, the brine could be pumped out of the cavern by means of a submersible pump and directed to disposal. Chemically compatible liquid and pumpable slurry wastes would then be inserted into the cavern. Displaced vapors and/or gases would be collected and would be either sent through a scrubber or burned in an approved flare as shown in Figure 15.

A cavern designed to be exposed to atmospheric pressure would be limited in size to maintain structural integrity. There would be no brine contamination, but a scrubber and flare would be required.

In-Situ-Solidified Waste Storage

Recently, officials of the state of Texas, who are responsible for permitting requirements for underground storage facilities, have been considering a concept that would require that all hazardous waste be mixed with a cement or polymer slurry prior to injection in a cavern as shown in Figure 16. This would provide a permanent solidified storage for liquid and slurry wastes and would reduce risks occasioned by earthquake or the inadvertent drilling into a hazardous waste cavern. This cavern would be limited in size in order to maintain structural integrity during the period that it would be exposed to atmospheric pressure.

"String-of-Pearls" Waste Storage Caverns

By constructing a series of caverns, one above the other, from one deep solution well, the dome salt resource could be more effectively utilized for a given maximum cavern depth as proposed by Empak, Inc. of Houston, Texas. Each cavern could be sealed by the installation of a cement plug in the top neck of the cavern, prior to starting construction of the next cavern above it as shown in Figure 17.

The brine from the first (bottom) cavern could be removed by submersible pump and directed to the remote brine disposal wells. This cavern would remain structurally stable due to its small size and because it would be filled

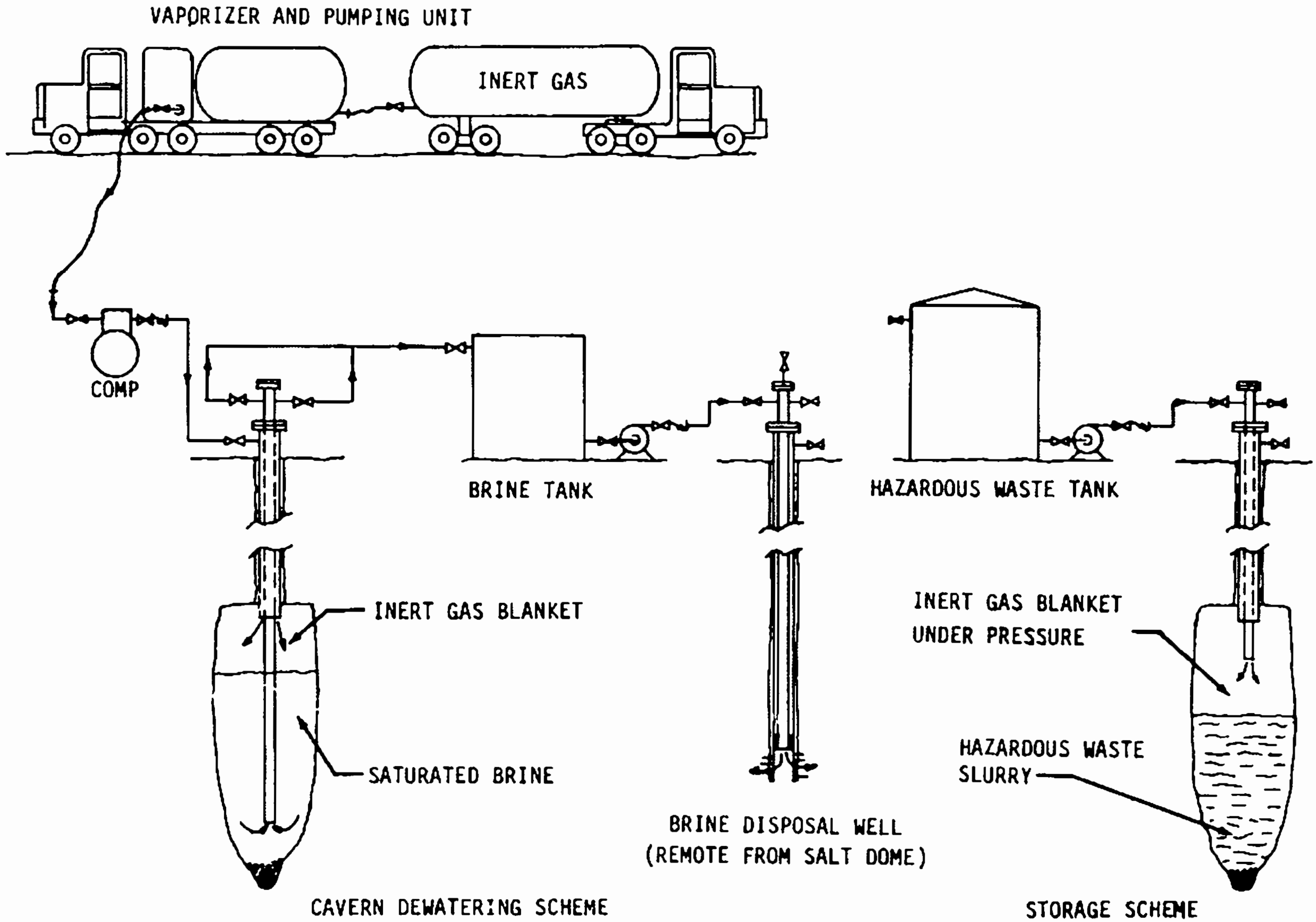

Figure 14 Gas-Balanced Cavern With Zero Discharge

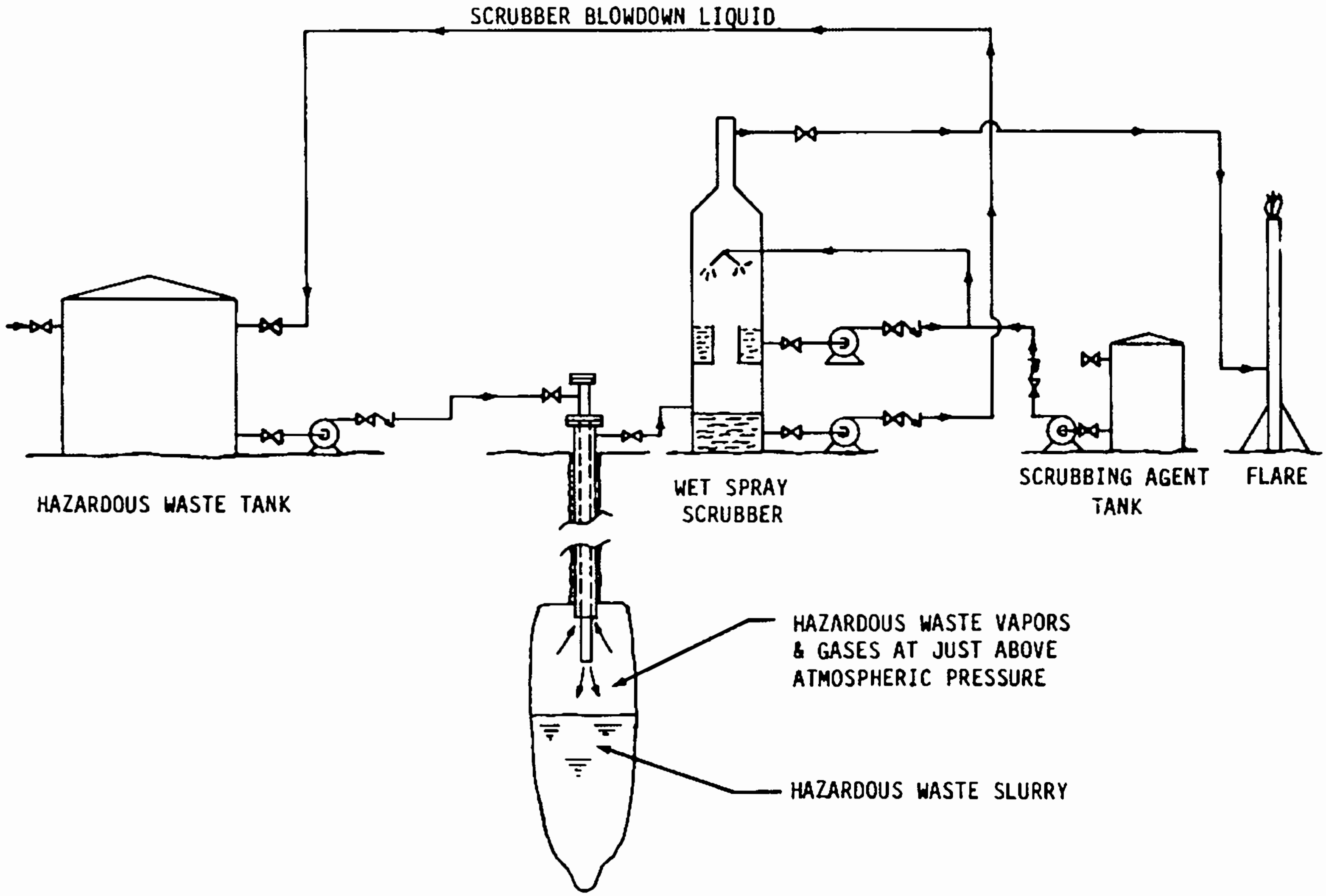

Figure 15 Atmospheric Cavern With Controlled Gas Discharge During Waste Injeccion

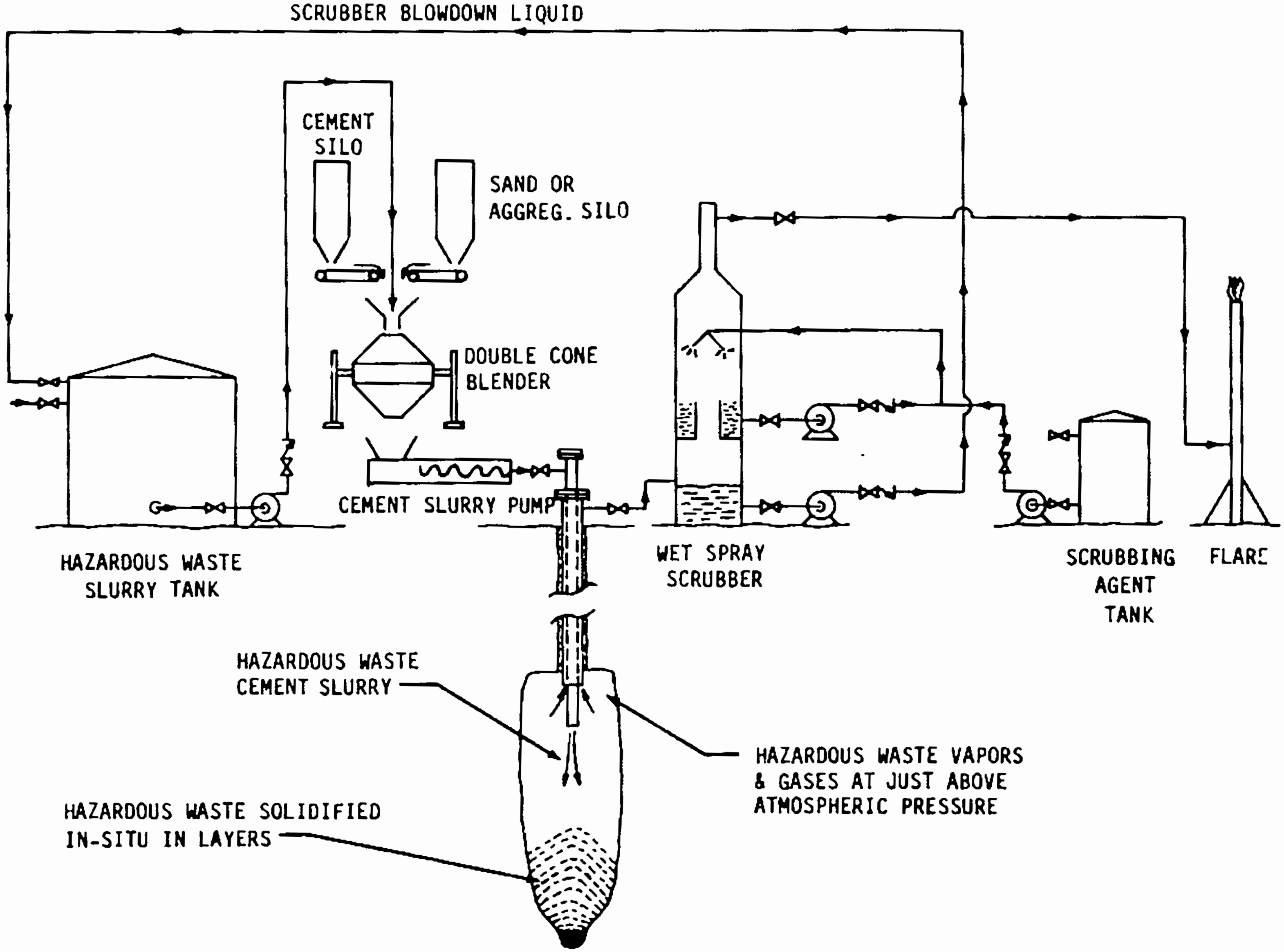

Figure 16 In-Situ - Solidified Hazardous Waste Storage

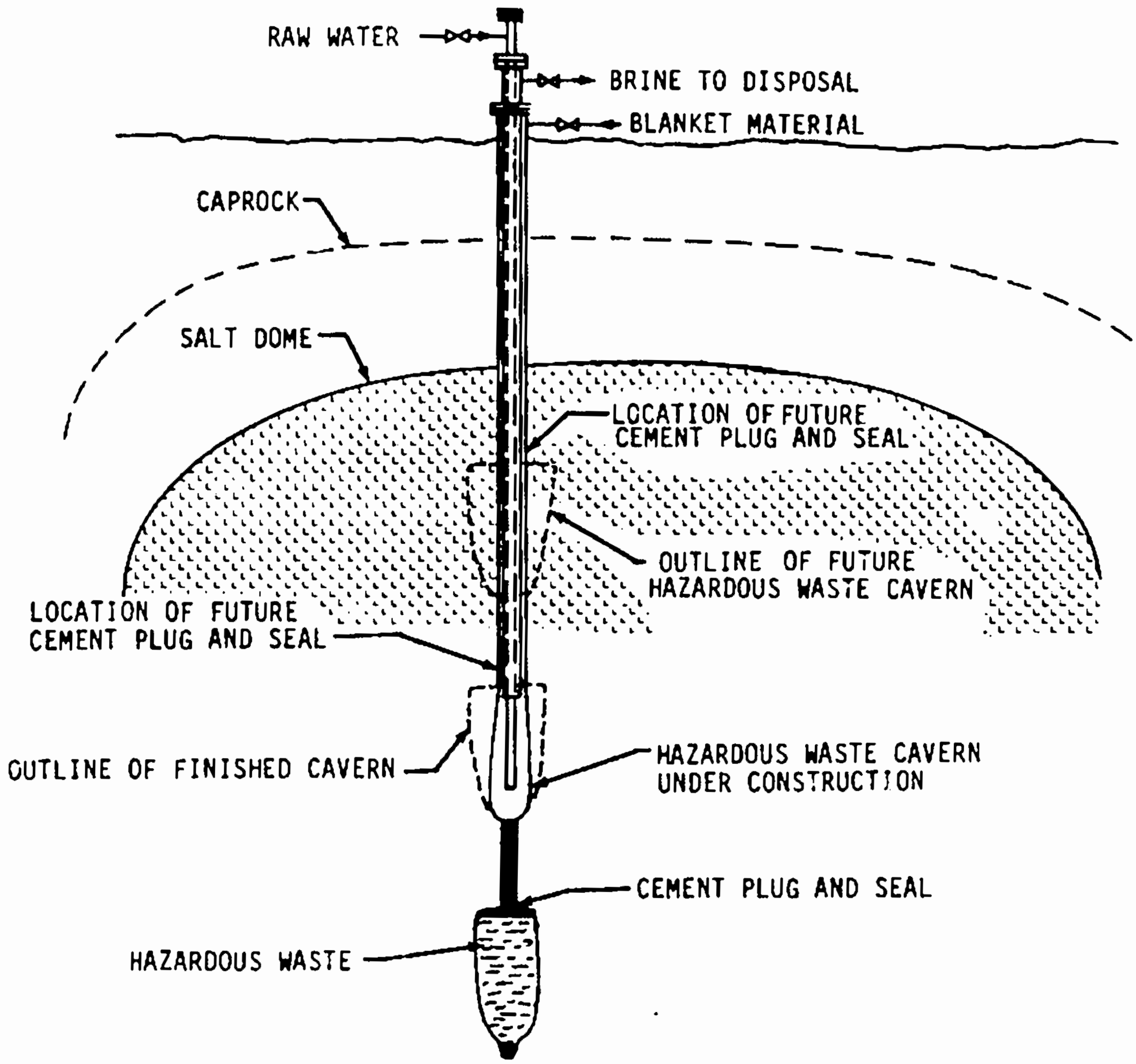

Figure 17 "String-of-Pearls" Waste Storage Caverns with waste relatively quickly, reducing the time that it would be exposed to near atmospheric pressure.

For maximum structural integrity into the future, all of the hazardous waste could be mixed with a cement slurry so that the entire small cavern would solidify as outlined by the proceeding method. Then construction of the small middle cavern could proceed as shown.

SECTION 11

DESIGN CONSIDERATIONS

Solution mined caverns for hazardous waste storage should provide absolute structural integrity and indefinitely long containment life. Large caverns are less expensive to construct per unit of volume than smaller ones, but they may not be as structurally adequate. Fracture-connected caverns in bedded salt may be leached much faster than single well caverns, but usually develop less desirable shapes. It is recommended that a conservative approach to solution mining hazardous waste caverns be used.

Feasibility Study

Following recognition of a need for a solution mined hazardous waste retention cavern in a particular area, a feasibility study should be conducted to determine the availability of salt, raw water for dissolution, and the possibilities for brine disposal. Geologic maps and well records of the area should be used to determine the solution mining potential. If the salt configuration or the acceptability of the proposed brine disposal formation were in doubt, one or more exploratory drill holes would be needed to produce rock cores for laboratory testing and allow flow testing of the disposal formation.

Salt Dome vs. Bedded Salt

In most cases, the desired location of the facility will dictate the type of salt formation available. In the event that both types of formations could be utilized, a salt dome would usually be preferable because of the potential for a much larger cavern with a corresponding reduction in the cost per unit of volume created.

Brine-Balanced Caverns

Brine-balanced caverns offer the most attractive means of waste retention, provided two requirements can be met:

- Injection of the waste material into the cavern would not contaminate the brine.
- The waste material must have a density and particle size that will permit gravity separation within a brine-filled cavern. A low density material would accumulate at the top of a cavern while high density material would fall to the bottom.

Such cavern would be operated by injecting waste slurry at the bottom or top of the cavern, depending on its density, and displacing brine from the opposite end. If liquid or slurry wastes, both heavier and lighter than saturated brine must be stored, two caverns would be required; one for the lighter wastes, and one for the heavier wastes. If the waste material arrived on site dry, or in a condition too thick to pump, some of the displaced brine could be used to prepare the proper slurry. The volume of the brine stream discharged to the deep injection well would equal the volume of waste slurry left in the cavern. If the slurry was an aqueous mixture, unsaturated with salt, a small amount of new cavern space would be created and the discharged volume of brine would be slightly less than the injected volume of slurry.

If the slurry was a non-aqueous mixture that would separate into liquid and solid components within the cavern, both could be contained, provided the fluid would not contaminate the brine.

Gas-Balanced Caverns

Natural gas caverns formed by solutioning are usually operated "dry." In this concept, natural gas is injected into the cavern at high pressure, displacing the brine to disposal. After the cavern has been dewatered, it is operated between a minimum and maximum wellhead pressure. Since salt tends to be somewhat plastic, it may tend to reduce the volume of the cavern if the cavern is very deep, and if the pressure is permitted to remain too low for too long a time period. This is often referred to as "closure." Although computer programs have been written to analyze "closure" type problems, experience remains the best teacher. Natural gas caverns are designed conservatively to provide absolute containment and indefinitely long containment life within the limitations of the salt.

A hazardous waste cavern could be operated "dry" in a manner similar to a natural gas cavern. At the completion of solutioning, the cavern would be full of clean saturated brine. Inert gas would then be injected by means of compressors, displacing brine to disposal. After this "dewatering" process, the cavern would be full of inert gas under pressure. Some of the inert gas would be released to the atmosphere until the lower design pressure of the cavern was reached. The cavern would then be ready to accept the hazardous waste as liquid or slurry. The cavern would continue to accept waste until the maximum design pressure of the cavern was reached. The initial low gas pressure might allow a small amount of cavern deformation by closure but adequate stability would be maintained.

The characteristic of closure, or plastic salt flow, is the key to the exceptional durability of solution mined hazardous waste caverns. Once a cavern has been filled with waste and the access hole properly plugged, stresses will gradually equalize.

Atmospheric Caverns

The few existing atmospheric, or nearly atmospheric solution mined caverns are used for the storage of condensate (natural gasoline). These caverns are in bedded salt at shallow depths and are relatively small. For condensate storage, the advantages of operation without a brine pond, and the reduced possibility of product contamination by the brine, outweigh the advantages of the conventional brine balanced method.

The atmospheric, or nearly atmospheric solution mined cavern method appears to be attractive for hazardous waste, because retrieval of the stored waste is not required and this method eliminates the possibility of contaminating the balancing brine. If the gases given off in the cavern can be chemically "scrubbed" and/or burned in an approved flare, the entire cavern could be used for liquid and slurry waste, improving the economics of the facility.

The structural integrity of an atmospheric, or nearly atmospheric solution mined cavern can be maintained during the one or two year time period when the cavern is being filled with waste, by limiting the depth to which the cavern is constructed and by limiting its diameter and height.

When the cavern becomes nearly full with waste, fresh saturated brine can be used to top off the cavern and a cement plug can be installed in the neck of the cavern. After the cement has been allowed time to cure, the plug can be pressure tested to confirm that the cavern has been sealed.

Solution mined caverns can be filled with hazardous waste at atmospheric pressure if they have been conservatively designed for this service.

Waste Forms

Solution mi[illegible] caverns could be used to contain any combination of gases, vapors, liquids, [illegible]ries, or in-situ solidifying slurry wastes depending on requirements.

If gases or vapors must be retained under pressure, the cavern must be designed accordingly.

If only liquid or slurry wastes are to be retained in the cavern, the atmospheric or nearly atmospheric pressure type of cavern could be utilized.

If in-situ solidifying wastes are to be retained, schemes must be developed for emplacing the slurry and cleaning the surface piping and well tubing prior to solidification so that it will be clear for the next emplacement cycle.

Pressure Considerations

Although the actual pressure at which a given formation will fracture varies rather widely, it is a common practice in industry to assume that a pressure gradient of 1 psi per foot of depth will fracture the formation at some location. This concept is being adopted by the state regulatory agencies who in turn, usually specify a maximum allowable pressure gradient of less than 1 psi per foot of depth. For example, Louisiana Statewide Order No. 29-M pertaining to the use of salt dome cavities for storage of liquid and/or gaseous hydrocarbons specifies that the maximum operating pressure at the casing seat shall not exceed 0.9 psi per foot of overburden.

The storage of high pressure natural gas in solution mined salt dome caverns requires a conservative approach. A commonly accepted pressure gradient for this service would be 0.85 psi per foot which should be adequate for hazardous waste retention in a salt dome.

A somewhat lower maximum pressure gradient is usually used in the design of bedded salt caverns due to the invariable presence of interbedded layers of shale or anhydrite and their unknown physical properties. A conservative maximum pressure gradient for a solution mined hazardous waste cavern in bedded salt would be 0.65 psi per foot of depth.

Table 9 outlines a comparison of a typical salt dome and bedded salt cavern retaining hazardous waste at atmospheric pressure.

TABLE 9

COMPARISON OF A TYPICAL SALT DOME AND
BEDDED SALT CAVERN RETAINING
HAZARDOUS WASTES AT ATMOSPHERIC PRESSURE

Cavern Feature	Salt Dome	Bedded Salt
Top of Salt to Top of Cavern, Ft.	400	30
Surface to Bottom of Cavern, Ft.	3,000	2,200
Cavern Height, Ft.	470	150
Cavern Diameter, Ft.	150	100
Net Capacity, Bbls.	1,000,000	100,000

These figures should not be taken as absolute limits, but rather as generalities to aid in visualizing the approximate number of caverns required for a given volume of waste.

Temperature Considerations

Excluding the Mississippi salt dome cavern detonations, most experience with elevated temperature in salt storage relates to natural gas or compressed air storage.

Examples of Temperature of Natural Gas and Compressed Air Injected into Storage Caverns:

o Huntorf Design	120°F	Northern Europe Salt Bed
o Valero Design	130°F	Southern U.S. Salt Dome
o Hornsea Project	104°F	Northern Europe Salt Bed
o Eminence Practice	160°F	Southern U.S. Salt Dome
o Tufco Practice	120°F	Southern U.S. Salt Dome

Unless the hazardous wastes to be placed into the cavern will exceed 150°F, conventional casing and cementing procedures should be adequate.

Underground Injection Control Program

All storage wells and brine disposal wells must meet the rules and regulations contained in the Federal Register, Vol. 49, No. 93, dated May 11, 1984 which covers Environmental Protection Agency 40 CFR Parts 124, 144, 146, and 147 regarding the Underground Injection Control Program. This program, whether implemented by the states or by the EPA, is designed to prevent underground injections through wells which may endanger drinking water sources.

Spacing Considerations

The State of Louisiana requires a minimum of 200 feet between adjacent caverns and at least 100 feet between a cavern and the property line. These spacing requirements should be adequate for hazardous waste storage. Drilling and solutioning tolerances must also be considered when determining cavern locations.

SECTION 12

OPERATIONAL CONSIDERATIONS FOR ATMOSPHERIC CAVERNS

It is anticipated that wastes would be delivered to the facility by truck. Prior to unloading a truck, the waste would be sampled to verify that it is the proper material specified by contract. This would be a quick "finger print" analysis. If the finger print analysis fails to match the contract, the load would be refused.

Transfer from the truck could be accomplished by unloading arms and automatic cut-off valves installed in the lines to prevent spillage of any waste material. The waste would be pumped to above-ground steel or fiberglass holding tanks and would be segregated in the holding tanks according to chemical characteristics. The wastes could be blended prior to being pumped to the appropriate cavern. Wastes which require special processing or neutralization would be handled separately. All waste handling facilities would be located on concrete pads with concrete containment dikes. Rainwater which accumulates within any of the concrete containment areas would be collected and disposed of with the waste material.

The temporary surface holding tanks could be vented through a scrubber system to control odorous or organic vapors. The truck unloading area and the holding tank area could be surrounded by concrete dikes allowing any spilled material to be quickly recovered and returned to storage. The waste water generated during truck cleaning could be collected and disposed of with the rest of the waste material. There would be no waste water discharge from the facility.

The actual transfer of waste in slurry form to the salt cavern could be made with the cavern pressure near atmospheric. A slight backpressure could be maintained to assist in directing waste vapors through the scrubber system. Vapors that could not be chemically scrubbed would be burned in an approved type flare.

The facility would be designed so that solutioning of new caverns could continue as the old caverns are being filled. This would develop storage as needed and would result in an economical operation.

SECTION 13

ENVIRONMENTAL, SOCIOLOGICAL, AND ECONOMIC CONSIDERATIONS

A hazardous waste retention facility must protect the environment at all times; during construction of the facility, during the process of adding waste to storage, and for an indefinite period of time into the future.

All aspects of the environment must be protected; the land, water, air, noise level, etc. Solution mining offers a unique solution to this requirement.

A minimum of land surface would be required for the concept. Many salt domes are relatively free of population and industry. The exceptions are industries utilizing the salt such as salt producers or hydrocarbon storage companies and on the flanks of some salt domes, drilling rigs.

Construction of the facility would have a minimal impact on the local area. Construction at the site would increase traffic and background noise slightly due to drilling, building, and tank erection activities and machinery operation.

Conservative design would prevent the possibility of subsidence.

Operation of the site should not have an adverse effect on water quality since there will be no discharge to surface waters.

The clean, saturated brine produced as a result of solutioning storage space could be injected into deep disposal wells.

The facility could be manned 24 hours per day, 7 days per week to provide constant monitoring.

Sources of air emissions from the facility would be limited to the diesel blanket storage tank.

Vapors displaced from the caverns would be chemically scrubbed or burned in an approved flare.

Careful siting of the facility would ensure no wildlife habitat would be disrupted in the immediate areas of construction of tanks, operational areas, and pipelines. Major facilities would be located in areas that are already relatively clear of vegetation. The storage facility would not be located in any wetlands area.

The proposed project would not interfere with oil and gas production or any scenic or other natural resource.

Construction of the facility would make use of services that are available in most areas such as general construction and oil field drilling. Once in operation, the facility would provide jobs for local residents as well as expand the local tax base.

The total impact on the local community would be expected to be beneficial because the dollars spent directly on the project would have an indirect multiplier effect for other goods and services.

SECTION 14

NEEDED RESEARCH

Solution mined salt caverns have been used for storage and disposal of certain hazardous wastes by industry for many years. The practice has been limited to compatible chemicals which are known to be nonreactive to each other and to the salt. One problem faced by the hazardous waste industry is the almost infinite mix of chemicals which occur in many waste discharges. Efforts have been made by the American Society of Testing Materials (ASTM) to determine compatibility of the various chemicals based upon theoretical analyses. This approach is helpful but all possible combinations may not have been adequately described and unexpected reactions may occur. When a commercial hazardous waste facility has many clients, each with a different waste stream, the potential for adverse reactions is multiplied many times if these waste streams are mixed together for a disposal operation. Thus, more research including both studies and actual tests of compatibility should be conducted for each combination of waste streams. When placed in the retention cavern, the waste will be in direct contact with the salt and with saturated brine. Research is needed to determine the analysis of salt cores taken from proposed solution cavern areas and to determine the compatibility of each with a mix of anticipated waste streams. If salt cores are not available from a given area, blocks of salt from a mine in the area could be substituted. Samples of typical waste streams could be obtained from commercial disposal operators or waste generators. These tests could be run in a laboratory under controlled conditions. Tests should be run on salts from the Permian basin and Salina basin, and at least two salt domes.

Solution mined salt caverns would be even more desirable for hazardous waste retention if a means could be developed to solidify the waste in-situ in the saturated brine storage cavern. Small scale research studies and laboratory tests are needed to develop salt saturated hazardous waste/cement or polymer slurry formulations that will have an acceptable fluidity during emplacement in the cavern, but that will develop adequate strength and long life with acceptable economy when solidified in the retention cavern. After the waste has been emplaced in the cavern, there must also be a practical way to flush the surface piping and well tubing before solidification occurs.

Preliminary feasibility studies including conceptual designs and order-of-magnitude cost estimates should be prepared for solution mined hazardous waste retention facilities using both dome and bedded salt formations. These studies should include an evaluation of waste form (i.e., solution, slurry, and/or in-situ solidification). These studies could provide a viable hazardous waste disposal scheme for the most difficult to manage wastes; wastes that remain after all economical means have been employed to prevent, reduce, neutralize, or otherwise render them non-hazardous.

SECTION 15

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APPENDIX A

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